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THROTTLABLE PRIMARY INJECTOR FOR STAGED COMBUSTION ENGINE

FINAL REPORT

Ronald A. Hankins
Michael Yankovich

Aerojet-General Corporation

TECHNICAL REPORT AFRPL-TR-70-40

June 1970

Air Force Rocket Propulsion Laboratory
Air Force Systems Command
United States Air Force
Edwards, California

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Michae! Yankovich

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FOREWORD

(U) This report describes the technical accomplishments of the Throttlable Primary Injector for Staged Combustion Engine Program of Project 3058, Contract F04611-69-C-0021. The period of performance for the technical effort was 1 November 1968 through 15 December 1969. The effort was directed toward demonstrating the throttling capability of a primary injector which would ultimately be incorporated into an advanced storable propellant space engine using the staged combustion cycle. Classified work related to this program was performed under Contracts AF 04(611)-10830(1) and F04611-68-C-0008(2).

(U) All work was performed at the Liquid Rocket Company of Aerojet-General Corporation for the Air Force Rocket Propulsion Laboratory at Edwards, California. Mr. R. A. Hankins was the Aerojet program manager; Mr. M. Yankovich was the Project Engineer. Mr. C. D. Penn was the Air Force project engineer.

This technical report has been reviewed and is approved.

C. D. Penn
Project Engineer
Liquid Rocket Division
Air Force Rocket Propulsion Laboratory
Edwards, California 93523

(1) Advanced Storable Rocket Engine - Storable, Phase I Final Report AFRPL-TR-67-75, August 1967

(2) Throttling and Scaling Study for Advanced Storable Engines, Report AFRPL-TR-68-2, January 1968

CONFIDENTIAL ABSTRACT

(U) This report summarizes the work performed under Contract F04611-69-C-0021, entitled "Throttlable Primary Injector for Staged Combustion Rocket Engine".

(U) The objective of this program was to demonstrate a throttlable primary injector for a storable space engine employing the staged combustion cycle. The program goal was to demonstrate throttling over a 10:1 range.

Specific accomplishments of the program were as follows:

(U) (1) Completed the detailed design of a flightweight modular primary injector for the storable space engine using the HIPERTHIN injector concept,

(C) (2) Demonstrated the injector over 90% of the desired throttling range (9K to 45K thrust),

(U) (3) Established critical design and fabrication parameters for the HIPERTHIN injector concept,

(C) (4) Demonstrated the performance of the HIPERTHIN injector through a chamber pressure range from 258 to 4390 psia and mixture ratio range from 10.7 to 27.0,

(C) (5) Demonstrated durability by conducting 87 tests with one injector in excess of 200 sec, with durations ranging from 10 sec at high thrust to 72 sec at low thrust,

(U) (6) Conducted supporting studies to provide additional design data in the areas of fluid flow and low frequency instability.

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APPENDIX

FIGURE LIST

FIGURE LIST (cont.)

TABLE LIST

LIST OF ABBREVIATIONS

$\dot{w}_f PC$	Flow rate, fuel flowmeter, primary combustor
$\dot{w}_o PC$	Flow rate, oxidizer flowmeter, primary combustor
PcPC	Pressure, chamber, primary combustor
Pc-H(P)	Pressure, high frequency Photocon
PFJ	Pressure, fuel injector manifold
PFJ-H(K)	Pressure, high frequency Kistler
PFJ-H(M)	Pressure, high frequency Microsystem
PFL	Pressure, fuel line
PFL-H(M)	Pressure, high frequency Microsystem
PFT	Pressure, fuel tank
POJ	Pressure, oxidizer injector manifold
POJ-H(K)	Pressure, high frequency Kistler
POJ-H(M)	Pressure, high frequency Microsystem
POL	Pressure, oxidizer line
POL-H(M)	Pressure, high frequency Microsystem
POT	Pressure, oxidizer tank
Pte	Pressure, turbine exit
Pti	Pressure, turbine inlet
TG	Temperature, gas side
TTI	Temperature, turbine inlet
SO/SF	Showerhead oxidizer/showerhead fuel
SO/IF	Showerhead oxidizer/impinging fuel
IO/IF	Impinging oxidizer/impinging fuel
DM	Dual manifold
MRPC	Mixture ratio Primary Combustor
MRSC	Mixture ratio Secondary Combustor
T_G	Temperature gas side
c*	characteristic velocity
c^*_{TH}	characteristic velocity theoretical
η_c	combustion efficiency

I. OBJECTIVE

(U) The objective of this program was to demonstrate a throttlable primary injector for a storable propellant (N_2O_4/AeroZINE 50*) space engine employing the staged-combustion cycle. Aerojet's MIST engine concept, which is designed to operate at high chamber pressures and over a 10:1 throttling range from 5000 to 50,000 lb thrust, was designated as the engine to be used in establishing the operating parameters and overall design configuration for the injector. The HIPERTHIN, or platelet injector concept, was to be utilized for the basic design. The program goal was to demonstrate a full scale injector over the 10:1 throttling range with the performance, stability, and gas temperature distribution characteristics obtained to be compatible with the MIST engine requirements.

II. PROGRAM SUMMARY

(U) The program was initiated on 1 November 1968 and was concluded on 15 December 1969. The program milestone chart is shown in Figure 1.

(U) The program was performed in two phases. Phase I included the injector and supporting hardware design and a segment test program where candidate HIPERTHIN injector designs were evaluated. Phase II was an evaluation of clustered injectors, the design of which was based on the Phase I test program results.

(U) Primary injector design criteria were established by the MIST engine design and operating specification, as well as practical constraints imposed by the HIPERTHIN-type construction. The MIST engine description and operating

*AeroZINE 50 (A-50) is a trademark registered by Aerojet-General describing a mixture of 50 w% hydrazine and 50 w% unsymmetrical dimethylhydrazine.

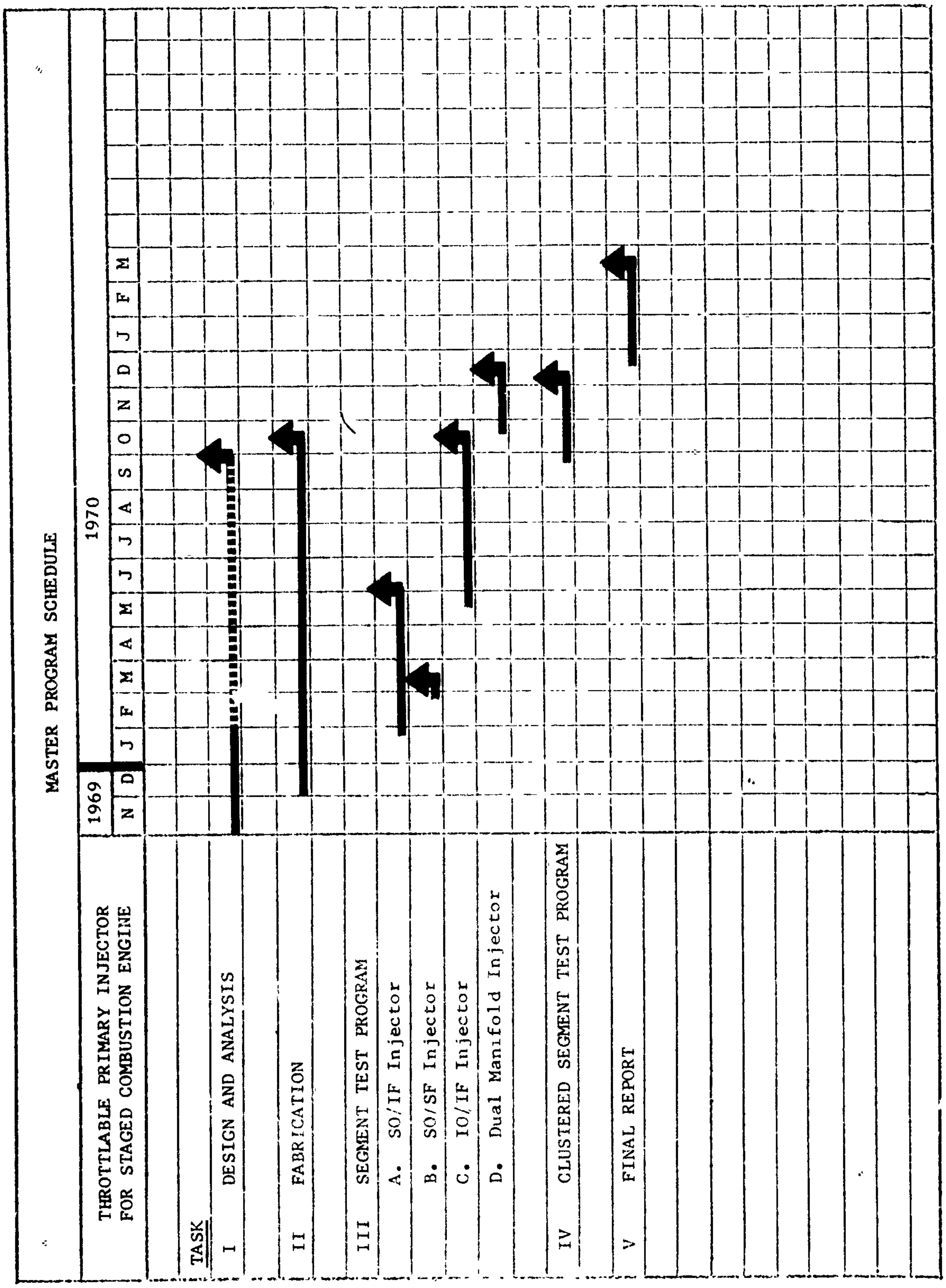


Figure 1. Program Milestone Chart

characteristics are described in detail in the appendix. Major primary combustor parameters, as defined by the engine power balance, are shown in Figure 2 over the thrust operating range. These relationships were established in part upon the results of a detailed performance analysis of the primary injector and combustion chamber.

A. PRIMARY INJECTOR DESIGN

(U) Early in the design phase of the program, several basically different HIPERTHIN injector configurations were studied with respect to pattern variation, versatility, ease of fabrication, cost, and packaging adaptability to the engine design. From this study, an injector of segmented design was selected. Ten identical segments or modules comprise the injector assembly; the segments are located circumferentially about the turbopump housing, in which the primary combustion chamber is located. Their location can be seen in Figure 3, a cut-away view of the MIST engine and in Figure A-1 of the Appendix, which is a photograph of the engine mockup. Selection of the modular approach allowed a single full scale segment to be used in the Phase I test program, thereby obviating the classic "subscale" approach with its attendant scaling problems. One of these injector segments, in the engine configuration, is shown in Figure 4.

(U) Four different HIPERTHIN injector patterns were designed, fabricated, and evaluated during the Phase I program. The first two patterns were evaluated concurrently during the initial part of the program, while the third and fourth patterns were iterations based upon test results. All injectors were of the same size and geometrical shape, having a rectangular face 1.75 inches in height by 2.00 inches in width. The injectors were of flightweight design except for an added flange to provide bolt-on capability for development testing.

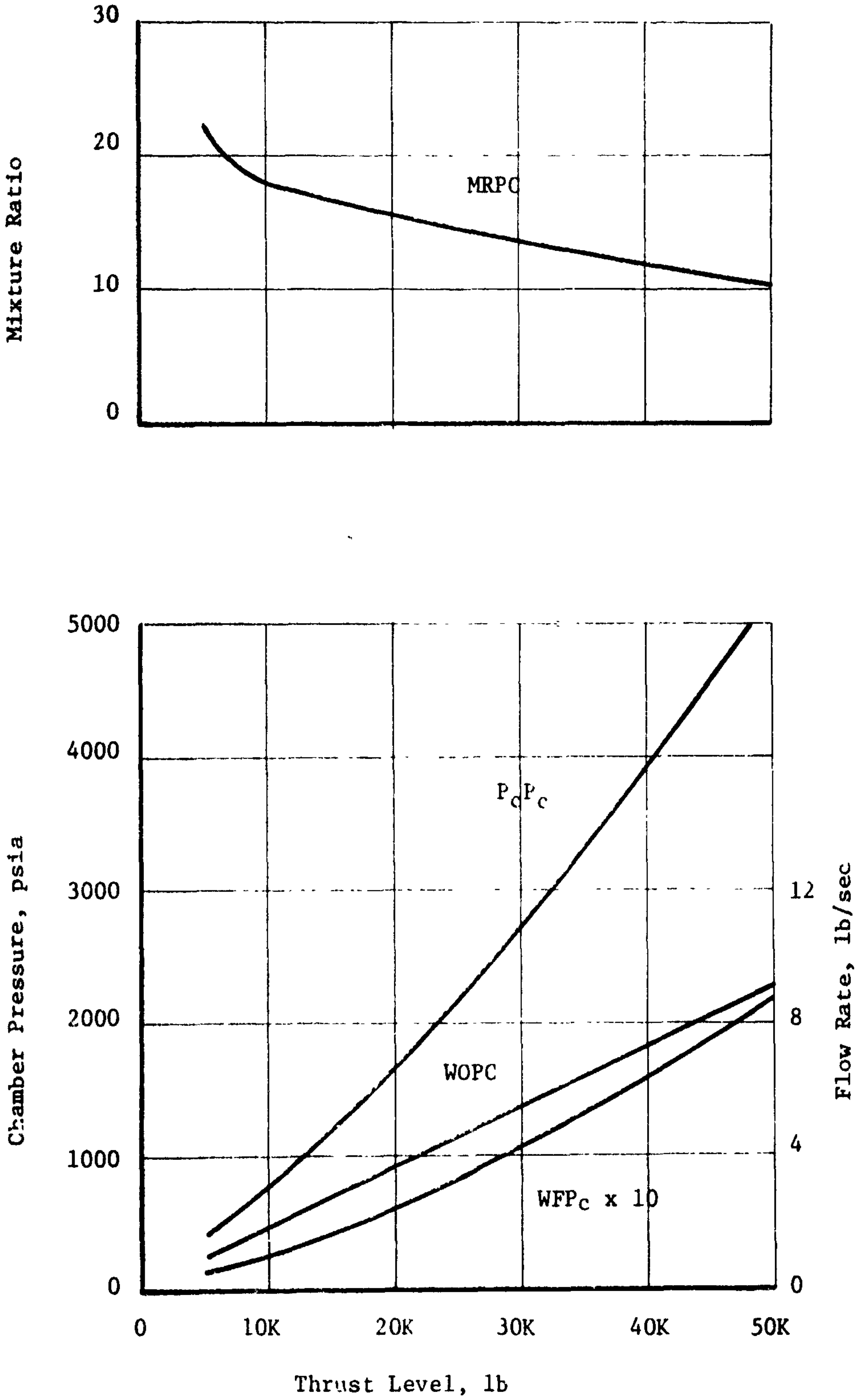
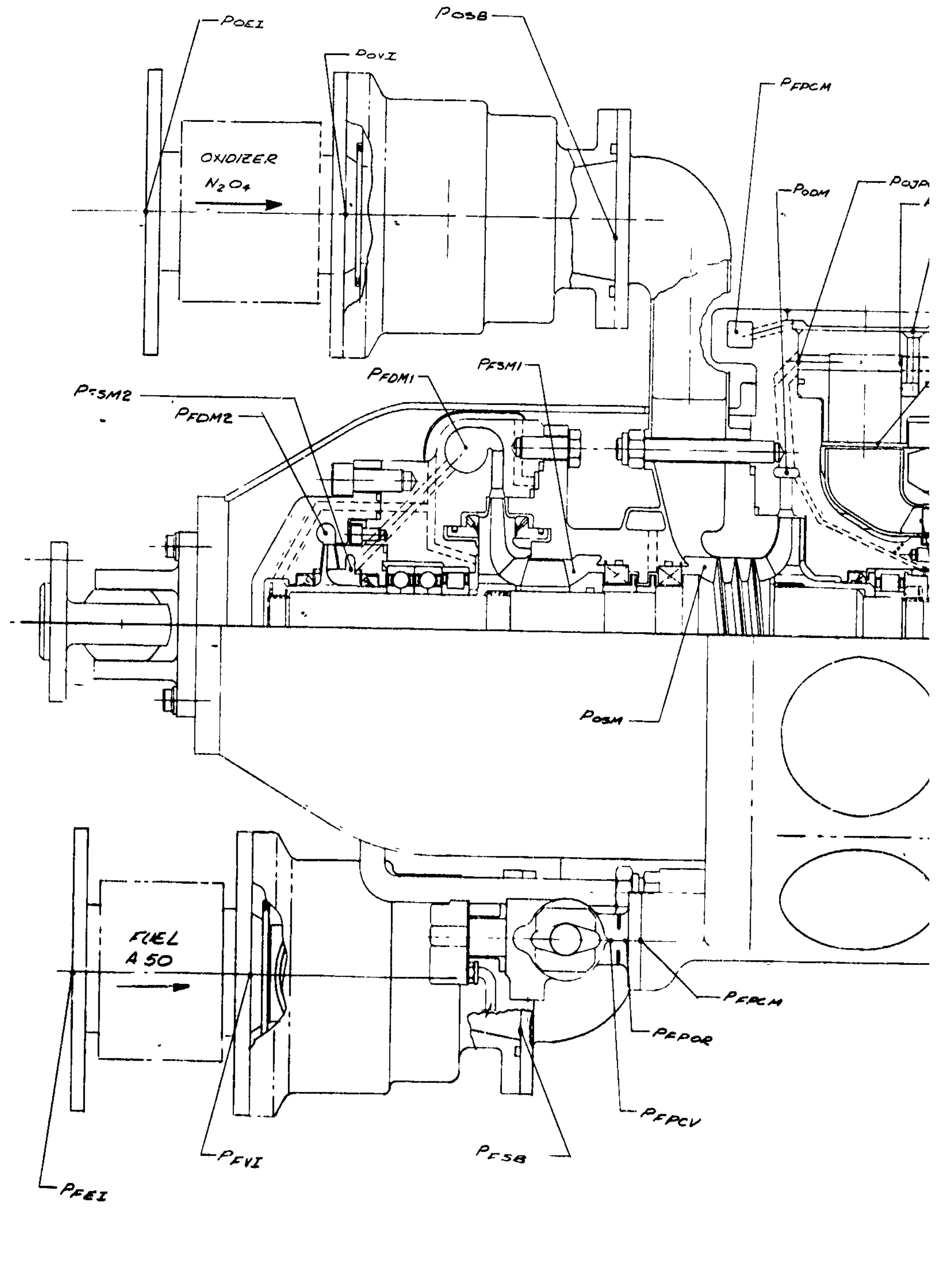


Figure 2. Primary Combustor Operating Parameters (2800 P_c Model)(U)


POEI
POVI
POSB
PFPCM
OXIDIZER
N_2O_4
PODM
PFSM2
PFDM2
PFDM1
PFSM1
POSM
FUEL
A 50
PFPCM
PFPOR
PFPCV
PFSB
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PFEI

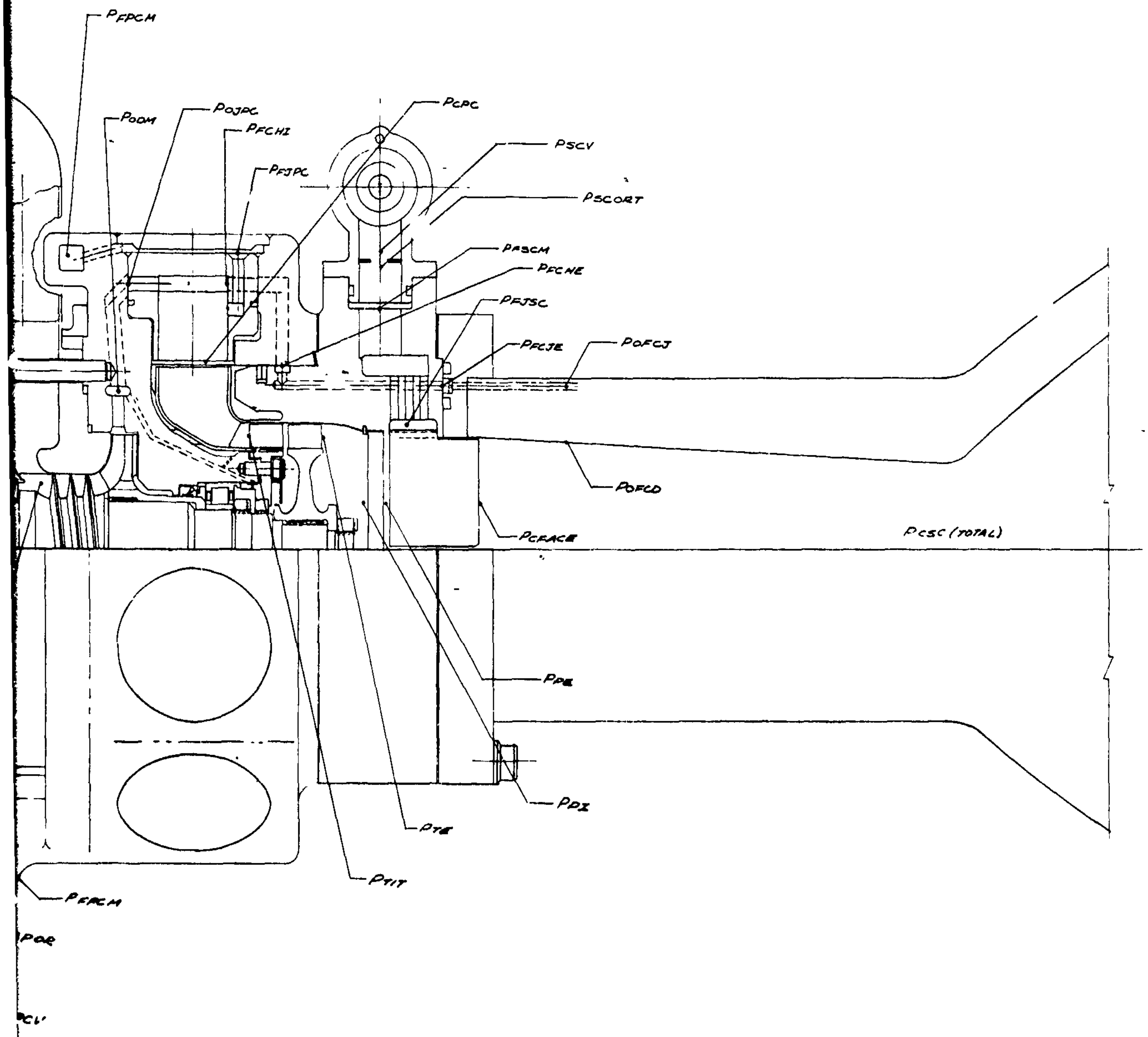


Figure 3. MIST Engine Model (U)

Figure 4. Development Injector

(C) The first injector pattern design featured both fuel and oxidizer showerhead orifices, while the second had the same oxidizer pattern but with impinging fuel orifices. Results of testing with these injector patterns disclosed that (1) the impinging fuel orifice design produced far smoother combustion than the showerhead pattern; and (2) higher circuit pressure drops were required to prevent low frequency oscillation at the lower thrust levels (below 18K). Based on this data, the third pattern was designed, in which the pressure drops in both circuits were increased. The oxidizer pattern was also converted to impinging orifice pairs in this redesign. During tests with this injector operation was excellent down to the 9K level, which represents over 90% of the intended throttling range. The fourth and final injector design retained the same face pattern as the third, but incorporated two fuel and two oxidizer circuits, with every other platelet being fed by an alternate manifold. In the lower throttling range, only one of the manifolds for each propellant would be used. Stable operation at the 5K and 7K levels was demonstrated with this injector configuration.

(C) The circuit pressure drops for the third and fourth patterns are higher than those currently used in the MIST engine models. For either of these injectors to be adopted into the engine, either the turbopump discharge pressure must be increased or the secondary chamber pressure reduced to 2400 psia. The latter would be the most probable course of action since it can be accomplished with a minimum redesign and does not significantly change engine performance or component packaging.

B. SEGMENT TEST PROGRAM

(C) The segment test program was initiated 27 January and concluded 12 December 1969. The program encompassed 176 tests, including basic injector

II, B, Segment Test Program (cont.)

evaluation tests and acceptance tests for the Phase II test program. The test data and results of each test are summarized in Table I. The SO/IF* injector was the first pattern evaluated. In the first test series of 49 tests with this injector, operation was evaluated at conditions equivalent to a thrust range of 10-44K. Operation throughout this range was satisfactory with respect to performance and structural integrity of the injector. However, at thrust levels of 18K and lower, pressure oscillations were encountered, being ±25% of nominal chamber pressure and at frequencies of 260 Hz at the 10K level, and ±12% and 450 Hz at the 18K level. At all thrust levels above 18K, no organized pressure oscillations were present; in fact, operation was very smooth, with chamber pressure oscillations being below ±1%. Tests were performed to determine if the oscillations were caused by coupling with the test stand feed system. It was determined that it was not, and that the unstable loop was between the combustion chamber and the injector feed manifolds.

(C) Thirty seven additional tests were then performed in which a resonator was attached to the combustion chamber in an attempt to suppress the oscillations. Using the resonator, stable operation was obtained at the 10K level; however, the resonator was highly selective as to the frequency it would damp, and since the combustion frequency changes with each thrust level, it was concluded that the best approach to eliminating the oscillations would be to redesign the injector, increasing circuit pressure drops to provide added injector "stiffness."

(C) Two tests were performed with the SO/SF injector, one at the 10K thrust level and one at 18K. In both tests combustion was very rough, with frequent intermittent "popping" in the combustion chamber, producing pressure

*Showerhead oxidizer/impinging fuel.

TABLE I

TEST DATA SUMMARY - SEGMENT PROGRAM (U)

	General Data			Measured Data											Performance Data					
Series	Test No. SP-30	S.S. Dur Sec	Inj. (1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	MR	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust Level Nominal	c* ft/sec	c*TH ft/sec	η_c	Stability (2)	Remarks
I	-101	-	SO/IF	701	1.96	0.110	2.070	13.3	786	803	-	-	-	10K	1255	2110	52.5	U-240	Initial checkout test
	-102	0.28	SO/IF	808	1.925	0.114	2.039	16.9	868	905	-	-	-	10K	1469	1790	82.0	U-240	MR survey
	-103	0.67	SO/IF	867	2.51	0.115	2.625	21.8	948	962	-	-	-	10K	1225	1480	82.6	U-240	MR survey
	-104	0.90	SO/IF	733	1.48	0.115	1.595	12.9	801	848	-	-	-	10K	1690	2160	78.2	U-240	MR survey
II	-105	1.35	SO/IF	1718	3.78	0.235	4.015	16.1	1848	1912	-	-	-	18K	1585	1855	85.5	S	Checkout test at 18K
	-106	1.36	SO/IF	1684	3.56	0.235	3.795	15.2	1814	188?	-	-	-	18K	1640	1930	84.9	S	MR survey
	-107	1.36	SO/IF	1655	3.34	0.235	3.575	14.2	1778	1856	-	-	-	18K	1710	2020	83.9	S	MR survey
	-108	9.36	SO/IF	1659	3.25	0.235	3.485	13.8	1785	1861	-	-	-	18K	1760	2060	85.3	Marginal	Long duration evaluation
	-109	2.10	SO/IF	1710	3.17	0.243	3.413	13.0	1804	1917	-	-	-	18K	1860	2140	86.8	S	Repeat Test 108 w/cavitating venturi
	-110	10.28	SO/IF	1704	3.27	0.241	3.511	13.6	1803	1900	-	-	-	18K	1800	2085	86.3	S	Duration demonstration
III	-111	0.66	SO/IF	2157	4.10	0.303	4.403	13.5	2290	2386	-	-	-	25K	1815	2095	88.2	S	Design MR demo. at 25K--blew gasket at 0.7 sec
	-112	-	SO/IF	Lost nozzle gasket - No valid data							-	-	-	25K	-	-	-	S	Low MR demo. Blew gasket before steady-state
	-113	2.03	SO/IF	2097	3.53	0.301	3.831	11.7	2202	2333	-	-	-	25K	2020	2310	87.7	S	Repeat Test 112
	-114	2.04	SO/IF	2144	4.43	0.289	4.719	15.4	2300	2350	-	-	-	25K	1683	1920	87.7	S	High MR demonstration
IV	-115	2.00	SO/SF	1800	3.22	0.234	3.454	13.8	-		-	-	-	18K	-	-	-	U-480	Showerhead pattern evaluation
V	-116	2.18	SO/IF	3221	5.52	0.444	5.964	12.4	3462	3595	-	-	-	37.5K	1990	2220	89.7	S	Design MR demonstration at 37.5K
	-117	9.63	SO/IF	3251	5.52	0.445	5.965	12.4	3489	3600	-	-	-	37.5K	2020	2220	91.0	S	Design MR duration demonstration
	-118	2.20	SO/IF	3245	5.10	0.450	5.550	11.3	3449	3603	-	-	-	37.5K	2165	2360	91.7	S	Low MR demonstration
VI	-119	2.10	SO/IF	3940	6.48	0.537	7.017	12.0	4246	4363	-	-	-	40K	2079	2270	91.6	S	Basic evaluation at 40K
	-120	2.10	SO/IF	4125	6.526	0.586	7.112	11.1	4440	4693	-	-	-	42K	2148	2400	89.6	S	Basic evaluation at 42K
	-121	2.10	SO/IF	4320	6.498	0.607	7.105	10.7	4640	4750	-	-	-	44K	2252	2460	91.5	S	Basic evaluation at 44K
	-122	2.20	SO/IF	Lost nozzle gasket - no valid data							-	-	-	-	-	-	-	S	Instrumented chamber

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

	General Data			Measured Data										Performance Data					
Series	Test No. SI-30	S.S. Dur Sec	Inj.(1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	MR	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust Level Nominal	c* ft/sec	c*TH ft/sec	η_c	Stability(2)	Remarks
VI	-123	9.20	SO/IF	4273	6.463	0.580	7.043	11.2	4578	4715	1207	1536	1928	44K	2245	2395	93.7	S	Long duration evaluation
	-124	0.55	SO/IF	4376	6.476	0.590	7.066	11.0	4741	4838	958	1132	1555	44K	2292	2420	94.7	S	15 grain pulse
	-125	9.60	SO/IF	4317	6.581	0.587	7.168	11.2	4624	4787	2200	1508	1769	44K	2228	2380	93.7	S	Reversed TG-1 and TG-3
	-126	9.60	SO/IF	4390	6.495	0.594	7.089	10.9	4689	4845	2260	1650	2004	44K	2292	2428	94.3	S	Repeat of 125 at reduced MR
VII	-127	19.20	SO/IF	2285	4.13	0.308	4.438	13.4	2413	2459	1495	1061	1284	25K	1900	2110	90.3	S	15 grain pulse
VIII	-128	1.10	SO/IF	800	1.935	0.112	2.047	17.3	-	-	483	471	352	10K	-	-	-	U-320	Evaluation at 10K
	-129	1.30	SO/IF	800	2.550	0.153	2.703	16.7	-	-	733	635	433	10K	-	-	-	U-360	10K evaluation at reduced MR
	-130	1.40	SO/IF	1700	3.040	0.198	3.238	15.3	-	-	976	1081	715	18K	-	-	-	U-440	Evaluation at 18K
	-131	1.50	SO/SF	800	1.970	0.113	2.083	17.4	-	-	562	518	390	18K	-	-	-	U-320	Showerhead fuel injector eval.
	-132	1.40	SO/IF	1700	3.220	0.238	3.458	13.5	-	-	932	1403	894	18K	-	-	-	U-430	Eval. at 18K - MR survey
	-133	1.40	SO/IF	1700	3.070	0.206	3.276	14.9	-	-	825	1039	623	18K	-	-	-	U-430	Eval. at 18K - MR survey
	-134	1.40	SO/IF	1700	3.210	0.236	3.446	13.6	-	-	862	1277	831	18K	-	-	-	U-400	Eval. at 18K - MR survey
	-135	2.00	SO/IF	1700	3.210	0.238	3.448	13.5	-	-	963	1266	676	18K	-	-	-	U-320	Moved venturis oxid-8 ft; fuel 14 ft
	-136	1.00	SO/IF	1466	3.190	0.237	3.427	13.4	-	-	998	1104	917	18K	-	-	-	U-480	Venturis returned to original position
	-137	1.00	SO/IF	1487	3.210	0.236	3.446	13.6	-	-	956	1057	788	18K	-	-	-	U-480	Further increased chamber nozzle diameter
	-138	1.00	SO/IF	1700	3.190	0.235	3.425	13.5	-	-	950	974	746	18K	-	-	-	U-480	Oxid. orifice 100 psi
	-139	1.00	SO/IF	1700	3.270	0.232	3.502	14.1	-	-	871	915	644	18K	-	-	-	U-500	Replaced venturis w/500 psi orif
	-140	2.00	SO/IF	1700	3.210	0.238	3.448	13.5	-	-	-	-	-	18K	-	-	-	U-450	Repeat Test 109
	-141	2.00	SO/IF	1700	3.190	0.238	3.428	13.4	-	-	-	-	-	18K	-	-	-	U-400	New configuration oxid inlet manifold
IX	-142	2.00	SO/IF	1870	Oxidizer leak - No valid data						-	-	-	18K	-	-	-	S	Chamb L* ext. eval. at 18K - Oxid leak
	-143	1.75	SO/IF	800	1.950	0.114	2.064	17.1	-	-	-	-	-	10K	-	-	-	U-250	L* section ext eval at 10K
	-144	1.75	SO/IF	800	1.950	0.113	2.063	17.1	-	-	-	-	-	10K	-	-	-	U-250	L* section w/increased nozzle dia

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

	General Data			Measured Data										Performance Data					
Series	Test No. SP-30	S.S. Dur Sec	Inj.(1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	MR	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust Level Nominal	c* ft/sec	c*TH ft/sec	η_c	Stability(2)	Remarks
IX	-145	1.90	SO/IF	1200	2.560	0.152	2.712	16.8	-	-	-	-	-	14K	-	-	-	U-340	L* section evaluation at 14K
	-146	2.00	SO/IF	1740	3.210	0.238	3.448	13.5	-	-	-	-	-	18K	1865	2100	89	S	Repeat of Test 142
	-147	2.00	SO/IF	2173	Oxidizer leak - no valid data						-	-	-	25K	-	-	-	S	L* Section; w/o venturi.
	-148	2.00	SO/IF	2285	Oxidizer leak - no valid data						-	-	-	25K	-	-	-	S	Repeat of Test 113 for stability verification
X	-149	2.10	SO/IF	1700	3.220	0.238	3.458	13.5	-	-	866	1071	836	18K	-	-	-	U-1100	Velocity incr turbulator eval.
	-150	2.10	SO/IF	1700	3.220	0.236	3.456	13.5	-	-	1022	1001	744	18K	-	-	-	U-460	Multihole orif turbulator eval.
	-151	2.10	SO/IF	1700	3.220	0.238	3.458	13.5	-	-	1020	840	872	18K	-	-	-	U-970	Double bar turbulator eval.
XI	-152	1.60	IO/IF	1680	3.12	0.236	3.356	13.2	1800	1920	1043	500	1320	18K	1850	2130	87.0	Stable	Redesigned injector (high ΔP)
	-153	2.90	IO/IF	870	2.02	0.120	2.140	16.8	-	-	340	307	-	10K	-	-	-	U-240	Redesigned injector (high ΔP)
	-154	2.50	IO/IF	1133	2.56	0.150	2.730	17.0	1226	1255	420	345	520	14K	1530	1780	86.0	Marginally Stable	Redesigned injector (high ΔP)
	-155	2.50	IO/IF	1080	2.44	0.144	2.584	16.9	1164	1200	405	343	494	14K	1540	1790	86.0	Marginally Stable	Redesigned injector (high ΔP)
	-156	2.50	IO/IF	1163	2.64	0.155	2.795	17.0	1262	1290	425	349	545	14K	1540	1780	86.5	Marginally Stable	Redesigned injector (high ΔP)
	-157	2.50	IO/IF	1002	2.72	0.136	2.456	17.0	1095	1120	355	319	-	12K	1510	1780	85.0	Marginally Stable	Redesigned injector (high ΔP)
XII	-158	1.65	SO/IF	-	Oxidizer and Fuel Leak - No Valid Data							-	-	10K	-	-	-	-	12-Hole reson, 1.00
	-159	1.65	SO/IF	700	1.880	0.105	1.985	17.9	-	-	310	350	425	10K	-	-	-	U-320	12-Hole reson, 1.00
	-160	1.65	SO/IF	715	1.910	0.106	2.016	18.0	-	-	280	360	405	10K	-	-	-	U-300	12-Hole reson, 1.00
	-161	1.65	SO/IF	730	1.895	0.104	1.999	18.2	-	-	280	355	410	10K	-	-	-	U-300	12-Hole reson, 0.800
	-162	1.65	SO/IF	735	1.920	0.104	2.024	18.4	-	-	265	385	350	10K	-	-	-	U-320	12-Hole reson, 0.700
	-163	1.65	SO/IF	735	1.920	0.105	2.025	18.3	-	-	250	305	310	10K	-	-	-	U-300	12-Hole reson, 0.600
	-164	1.65	SO/IF	760	1.920	0.105	2.025	18.3	-	-	260	330	350	10K	-	-	-	U-300	12-Hole reson, 0.500
	-165	1.65	SO/IF	770	1.920	0.105	2.025	18.3	-	-	260	325	320	10K	-	-	-	U-300	12-Hole reson, 0.550
	-166	1.65	SO/IF	770	1.910	0.105	2.015	18.2	-	-	250	300	285	10K	1410	1700	83.0	Stable	12-Hole reson, 0.650

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

General Data				Measured Data										Performance Data					
Series	Test No. SP-30	S.S. Dur Sec	Inj.(1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	MR	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust Level Nominal	c* ft/sec	c*TH ft/sec	η_c	Stability(2)	Remarks
XII	-167	1.65	SO/IF	765	1.910	0.104	2.014	18.4	-	-	250	295	230	10K	1400	1685	83.5	Stable	12-Hole reson, 0.625
	-168	1.65	SO/IF	-	Hot Gas Leak - No Valid Data					-	-	-	-	10K	-	-	-	-	12-Hole reson, 0.625 in.; L*
	-169	1.65	SO/IF	750	1.920	0.102	2.022	18.7	-	-	300	345	340	10K	-	-	-	U-280	4-Hole resonator, 0.300 in.
	-170	1.65	SO/IF	750	1.920	0.103	2.023	18.6	-	-	305	345	450	10K	-	-	-	U-280	4-Hole resonator; 0.250 in.
	-171	1.65	SO/IF	745	1.89	0.103	1.993	18.3	-	-	315	345		10K	-	-	-	U-280	4-Hole resonator, 0.200 in.
	-172	1.65	SO/IF	740	1.89	0.102	1.992	18.5	-	-	315	345	-	10K	-	-	-	U-280	4-Hole resonator, 0.150 in.
	-173	1.65	SO/IF	745	1.89	0.103	1.993	18.3	-	-	275	350	-	10K	-	-	-	U-280	4-Hole resonator, 0.000 in.
	-174	1.65	SO/IF	750	1.90	0.103	2.003	18.4	-	-	310	345	-	10K	-	-	-	U-280	4-Hole resonator, 0.400 in.
	-175	1.65	SO/IF	750	1.90	0.103	2.003	18.4	-	-	285	345	326	10K	-	-	-	U-440	8-Hole resonator, 0.600 in.
	-176	1.65	SO/IF	750	1.92	0.102	2.022	18.7	-	-	280	360	310	10K	-	-	-	U-440	8-Hole resonator, 0.500 in.
	-177	1.65	SO/IF	750	1.92	0.102	2.022	18.7	-	-	285	355	305	10K	-	-	-	U-340	8-Hole resonator, 0.400 in.
	-178	1.65	SO/IF	745	1.90	0.102	2.002	18.6	-	-	285	350	305	10K	-	-	-	U-340	8-Hole resonator, 0.450 in.
	-179	1.65	SO/IF	745	1.90	0.102	2.002	18.6	-	-	278	346	325	10K	-	-	-	U-340	8-Hole resonator, 0.700 in.
	-180	1.65	SO/IF	745	1.89	0.102	1.992	18.5	-	-	285	350	320	10K	-	-	-	U-340	8-Hole resonator, 0.800 in.
	-181	1.65	SO/IF	694	1.89	0.102	1.992	18.5	-	-	276	350	290	10K	-	-	-	U-250	8-Hole resonator, 0.500 in.; L*
	-182	1.65	SO/IF	710	1.89	0.102	1.992	18.5	-	-	260	345	321	10K	-	-	-	U-200	8-Hole resonator, 0.550 in.; L*
	-183	1.65	SO/IF	730	1.84	0.102	1.942	18.0	-	-	250	450	310	10K	-	-	-	U-180	12-Hole resonator, 0.625 in.
	-184	1.65	SO/IF	730	1.79	0.102	1.892	17.5	-	-	260	345	380	10K	-	-	-	U-200	12-Hole resonator, 0.525 in.
	-185	1.65	SO/IF	720	1.79	0.102	1.892	17.5	-	-	250	370	330	10K	-	-	-	U-180	12-Hole resonator, 0.425 in.
	-186	1.65	SO/IF	730	1.80	0.102	1.902	17.6	-	-	300	365	410	10K	-	-	-	U-200	12-Hole resonator, 0.800 in.
	-187	1.65	SO/IF	760	1.80	0.102	1.902	17.6	-	-	255	300	330	10K	-	-	-	U-340	12-Hole resonator, 1.00 in.

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

Series	Test No. SP-30	S.S. Dur sec	Inj.(1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	M.R.	P_{oJ} psia	P_{fJ} psia	TC-1 °F	TC-2 °F	TC-3 °F	Thrust Level Nominal	c* ft/sec	c* TH ft/sec	η_c	Stability(2)	Remarks
	General Data			Measured Data										Performance Data					
XII	188	1.65	SO/IF	750	1.89	0.102	1.992	18.5	-	-	255	330	385	10K	-	-	-	U-320	12-Hole resonator, 0.625 in.
	189	1.65	SO/IF	750	1.89	0.102	1.992	18.5	-	-	295	340	350	10K	-	-	-	U-240	12-Hole resonator, 0.550 in.
	190	1.65	SO/IF	750	1.90	0.102	2.002	18.6	-	-	265	340	385	10K	-	-	-	U-320	12-Hole resonator, 0.800 in.
	191	1.65	SO/IF	750	1.90	0.102	2.002	18.6	-	-	260	330	385	10K	-	-	-	U-320	12-Hole resonator, 0.700 in.
	192	1.65	SO/IF	750	1.90	0.102	2.002	18.6	-	-	260	320	355	10K	-	-	-	U-320	12-Hole resonator, 0.650 in.
	193	1.65	SO/IF	750	1.90	0.102	2.002	18.6	-	-	270	335	350	10K	-	-	-	U-Random	12-Hole resonator, 0.600 in.
	194	1.65	SO/IF	1090	2.58	0.151	2.731	17.1	-	-	345	450	670	14K	-	-	-	U-360	12-Hole resonator, 0.625 in.
XIII	195	2.5	IO/IF-2	710±15%	1.92	0.091	2.01	21.1	792	806	254	-	-	10K	-	-	-	U-250	Modified IO/IF injector Eval. at 10K w/o L*
	196	2.5	IO/IF-2	797±14%	2.22	N.G.	2.30	-	902	909	267	-	-	12K	-	-	-	U-250	Eval. at 12K w/o L*
	197	2.5	IO/IF-2	884±13%	1.93	0.121	2.05	16.0	969	1016	304	-	-	10K	-	-	-	U-270	Low M.R. eval. w/o L*
	198	2.5	IO/IF-2	727±1%	1.92	0.091	2.01	21.1	807	824	260	-	-	10K	1335	1520	87.7	Stable	L* eval. at 10K
	199	10.0	IO/IF-2	723±1%	1.89	0.090	1.98	21.0	806	824	265	-	-	10K	1350	1530	88.2	Stable	10K long duration w/L*
	200	2.5	IO/IF-2	1058±2.8%	2.54	0.140	2.68	18.1	1173	1203	325	-	-	14K	1460	1700	85.8	Marg. S	14K eval. w/o L*
	201	2.5	IO/IF-2	1125±2.2%	2.70	0.147	2.85	18.3	1254	1277	340	-	-	15K	1460	1690	86.4	Marg. S	15K eval. w/o L*
	202	2.5	IO/IF-2	330±15%	0.993	0.040	1.03	24.8	366	371	195	-	-	5K	-	-	-	U-110	5K eval. w/L*
	203	2.5	IO/IF-2	510±10%	1.42	0.063	1.48	22.5	561	569	225	-	-	7.5K	-	-	-	U-180	7.5K eval. w/L*
	204	2.5	IO/IF-2	711±1%	1.84	0.090	1.93	20.4	780	802	265	-	-	10K	1360	1580	86.0	Stable	10K eval. w/L*
	205	2.5	IO/IF-2	599±4.1%	1.62	0.075	1.70	21.6	659	672	240	-	-	8.5K	1300	1500	86.7	Marg. S	8.5K eval. w/L*
	206	10.0	IO/IF-2	618±1.6%	1.71	0.077	1.79	22.2	682	694	246	-	-	9K	1275	1470	86.7	Stable	Long dur. eval. at 9K w/L*
	207	72.0	IO/IF-2	622±1.6%	1.74	0.078	1.82	22.2	685	701	324	317	333	9K	1260	1470	85.8	Stable	9K thrust demonstration test w/pulse, w/L*
	208	2.5	IO/IF-2	2274±1%	4.48	0.293	4.77	15.3	2550	2631	800	815	900	27K	1770	1920	92.1	Stable	25K checkout test, w/L*
	209	23.0	IO/IF-2	1800±1%	4.43	0.290	4.71	15.3	2073	2140	850	802	912	25K	-	-	-	Stable	25K thrust demonstration test w/pulse-gasket leak, w/L*

(1) SO/IF: Showerhead oxid, impinging fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

Series	Test No. SP-30	General Data: S.S. Dur sec	Inj.(1)	Measured Data: P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	M.R.	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Performance Data: Thrust Level Nominal	c* ft/sec	c* TH ft/sec	η_c	Stability(2)	Remarks
XIII	210	2.5	IO/IF-2	2800±1%	6.95	0.530	7.480	13.1	-	-	981	-	1110	35K	-	-	-	Stable	40K checkout test - gasket leaked, w/L*
	211	10.5	IO/IF-2	2200±1%	7.05	0.545	7.648	13.0	-	-	1060	-	1100	27K	-	-	-	Stable	40K demo. attempt - gasket leaked, w/L*
	212	10.5	IO/IF-2	3818±1%	7.31	0.556	7.866	13.1	4482	4583	976	-	1139	42K	1795	2120	84.7	Stable	40K demo. test w/pulse, w/L*
	213	4.40	IO/IF-2	1689	3.66	0.212	3.872	17.2	1936	1880	-	737	685	22K	1610	1760	91.5	Stable	Initiation of acceptance testing clustered seg. inj SN 001
	214	4.40	IO/IF-2	1695	3.66	0.216	3.876	16.9	1937	1883	-	752	701	22K	1618	1790	91.8	Stable	SN 001
	215	4.40	IO/IF-2	1689	3.66	0.213	3.873	17.2	1928	1880	802	-	693	22K	1610	1760	91.5	Stable	SN 002
	216	4.40	IO/IF-2	1692	3.66	0.215	3.875	17.0	1906	1883	755	-	739	22K	1615	1780	90.9	Stable	SN 003
	217	4.40	IO/IF-2	1669	3.66	0.208	3.868	17.5	1883	1847	745	712	707	22K	1590	1740	91.5	Stable	SN 006
	218	4.40	IO/IF-2	1703	3.70	0.216	3.916	17.1	1919	1925	-	716	701	22K	1610	1770	91.0	Stable	SN 009
	220	4.56	IO/IF-2	1699	3.67	0.213	3.883	17.2	1956	1845	-	701	-	22K	1615	1760	91.8	Stable	SN 013
	221	4.56	IO/IF-2	1706	3.68	0.216	3.896	17.0	1966	1858	-	710	-	22K	1620	1780	91.0	Stable	SN 014
	222	4.56	IO/IF-2	1705	3.64	0.214	3.854	17.0	1936	1855	-	728	753	22K	1635	1780	92.0	Stable	SN 015
	223	4.56	IO/IF-2	1710	3.64	0.215	3.855	16.9	1948	1855	-	735	747	22K	1640	1790	91.8	Stable	SN 016
	224	4.56	IO/IF-2	1714	3.64	0.216	3.856	16.8	1894	1872	-	738	723	22K	1645	1800	91.5	Stable	SN 017
	225	4.56	IO/IF-2	1695	3.72	0.212	3.932	17.5	1956	1858	-	680	697	22K	1595	1740	90.8	Stable	SN 013
	226	4.23	IO/IF-2	1709	3.71	0.215	3.925	17.2	1951	2010	-	696	733	22K	1610	1760	91.5	Stable	SN 004
	227	4.23	IO/IF-2		Invalid Data - Fuel Leak Injector Inlet Line									22K				Stable	SN 005
	228	4.23	IO/IF-2		Invalid Data - Oxid. Leak Injector O-Ring Seal									22K				Stable	SN 007
	229	4.24	IO/IF-2	1425	3.67	0.216	3.886	17.0	1661	1704	835	695	672	20K	1610	1780	90.5	Stable	SN 007
	230	4.24	IO/IF-2	1417	3.68	0.214	3.894	17.2	1674	1592	774	724	698	20K	1590	1760	90.5	Stable	SN 008
	231	4.24	IO/IF-2	1427	3.68	0.214	3.894	17.2	1669	1599	744	710	651	20K	1605	1760	91.2	Stable	SN 011

(1) SO/IF: Impinging oxid, showerhead fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

Series	Test No. SP-30	S.S. Dur sec	Inj.(1)	P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	M.R.	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Thrust Level Nominal	c* ft/sec	c* TH ft/sec	η_c	Stability(2)	Remarks
	General Data			Measured Data										Performance Data					
XIV	232	4.24	IO/IF-2	1437	3.68	0.215	3.895	17.1	1669	1585	844	721	704	20K	1615	1770	91.3	Stable	SN 013
	233	4.24	IO/IF-2	1423	3.66	0.214	3.874	17.1	1653	1573	716	729	693	20K	1605	1770	90.7	Stable	SN 014
	234	4.24	IO/IF-2	1423	3.66	0.215	3.875	17.0	1680	1617	725	733	702	20K	1605	1780	90.2	Stable	SN 005
	235	4.24	IO/IF-2	1427	3.61	0.215	3.825	16.8	1629	1601	-	740	696	20K	1630	1800	90.7	Stable	SN 006
	236	4.24	IO/IF-2	1431	3.61	0.215	3.825	16.8	1672	1611	-	720	658	20K	1635	1800	91.0	Stable	SN 011; 0.144 in. dia. fuel orifice
	237	4.24	IO/IF-2	1431	3.70	0.215	3.915	17.2	1664	1602	-	719	659	20K	1600	1760	91.0	Stable	SN 013; 0.120 in. dia. fuel orifice
	238	4.24	IO/IF-2	1425	3.70	0.213	3.913	17.3	1650	1611	-	721	693	20K	1600	1760	91.0	Stable	SN 013; 0.092 in. dia. fuel orifice
	239	2.44	IO/IF-2	1433	3.70	0.216	3.916	17.1	1678	1618	-	704	638	20K	1605	1770	90.7	Stable	SN 011
	240	2.44	IO/IF-2	1439	3.68	0.215	3.895	17.1	1676	1618	-	712	685	20K	1615	1770	91.3	Stable	SN 013; 0.120 in. dia. fuel orifice
	241	2.44	IO/IF-2	1426	3.68	0.215	3.895	17.1	1653	1593	-	698	672	20K	1605	1770	90.7	Stable	SN 015; 0.116 in. dia fuel orifice
	242	2.44	IO/IF-2	1433	3.68	0.215	3.895	17.1	1664	1619	-	710	685	20K	1610	1770	91.3	Stable	SN 015; 0.092 in. dia. fuel orifice
	243	2.44	IO/IF-2	1432	3.67	0.216	3.886	16.9	1648	1620	-	710	672	20K	1615	1790	90.2	Stable	SN 006: 0.144 in. dia. fuel orifice; 0.454 in. dia. oxid. orifice
	244	2.44	IO/IF-2	1429	3.64	0.215	3.855	16.9	1649	1614	-	710	672	20K	1610	1790	90.6	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.422 in. dia. oxid orif.
	245	2.44	IO/IF-2	1427	3.67	0.213	3.883	17.1	1654	1608	-	734	688	20K	1610	1770	91.3	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.377 in. oxid. orif.
	246	2.44	IO/IF-2	1430	3.72	0.215	3.935	17.3	1694	1630	-	674	636	20K	1610	1760	91.5	Stable	SN 006; 0.144 in. dia. fuel orif.; 0.340 in. dia. oxid. orif.
	247	2.44	IO/IF-2	1428	3.69	0.215	3.905	17.1	1684	1628	-	659	642	20K	1600	1770	90.5	Stable	SN 003; 0.343 in. dia. oxid orif.
	248	2.44	IO/IF-2	1426	3.71	0.215	3.925	17.2	1670	1628	-	685	662	20K	1590	1760	90.5	Stable	SN 003; 0.377 in. dia. oxid. orif.
	249	2.36	IO/IF-2	1395	3.68	0.215	3.895	17.1	1629	1644	827	755	531	20K	1570	1770	88.7	Stable	SN 010
	250	2.36	IO/IF-2	1391	3.72	0.214	3.935	17.3	1572	1555	809	753	563	20K	1550	1760	88.2	Stable	SN 018
	251	2.36	IO/IF-2	1391	3.68	0.219	3.899	16.8	1564	1568	816	803	475	20K	1565	1800	87.0	Stable	SN 019
	252	2.36	IO/IF-2	1395	3.69	0.219	3.909	16.8	1583	1614	656	685	580	20K	1565	1800	87.0	Stable	SN 020

(1) SO/IF; impinging oxid, showerhead fuel; SO/SF: showerhead oxid, showerhead fuel.
(2) Unstable tests show predominant frequency noted in chamber pressure.

TABLE I (cont.)

Series	Test No. SP-30	General Data: S.S. Dur sec	Inj.(1)	Measured Data: P_c psia	$\dot{w}_o$ lb/sec	$\dot{w}_f$ lb/sec	$\dot{w}_t$ lb/sec	M.R.	P_{oJ} psia	P_{fJ} psia	TG-1 °F	TG-2 °F	TG-3 °F	Performance Data: Thrust Level Nominal	c* ft/sec	c* TH ft/sec	η_c	Stability(2)	Remarks
XIV	253	2.36	IO/IF-2	1396	3.72	0.219	2.939	17.0	1584	1593	905	828	449	20K	1550	1780	87.2	Stable	SN 021
	254	2.36	IO/IF-2	1399	3.73	0.219	3.949	17.0	1578	1568	850	790	524	20K	1550	1780	87.2	U-1120	SN 022; no turbine simulator orifice used
	255	2.36	IO/IF-2	1390	3.66	0.213	3.873	17.2	1567	1551	837	812	458	20K	1570	1760	89.4	Stable	SN 023; no turbine simulator orifice used
	256	1.26	IO/IF-2	1400	3.70	0.215	3.915	17.2	1568	1562	560	756	559	20K	1570	1760	89.4	U-1120	SN 024; no turbine simulator orifice used
	257	2.15	IO/IF-2	1460	3.74	0.214	3.954	17.5	1690	1690	1653	1817	1939	20K	1615	1740	92.8	Stable	SN 012; fuel rich start and shutdown
	258	2.15	IO/IF-2	1474	3.74	0.214	3.954	17.5	1716	1712	1771	1913	1985	20K	1630	1740	93.8	Stable	SN 017; fuel rich start and shutdown
	259	2.30	IO/IF-2	1481	3.68	0.215	3.895	17.1	1725	1717	714	705	663	20K	1565	1770	94.2	Stable	SN 012
	260	2.30	IO/IF-2	1480	3.69	0.214	3,904	17.2	1705	1691	658	710	713	20K	1660	1760	94.2	Stable	SN 018
	261	2.30	IO/IF-2	1479	3.72	0.214	3.934	17.4	1699	1705	652	710	721	20K	1645	1750	94.0	Stable	SN 019
	262	2.30	IO/IF-2	1488	3.68	0.214	3.894	17.2	1713	1727	649	718	738	20K	1670	1760	95.0	Stable	SN 020
	263	2.30	IO/IF-2	1467	3.70	0.211	3.911	17.5	1701	1715	703	701	651	20K	1640	1740	94.3	Stable	SN 020
	264	2.30	IO/IF-2	1472	3.70	0.214	3.914	17.3	1699	1692	680	710	682	20K	1650	1760	93.7	Stable	SN 023
XV	265	-	DM	-	-	-	No Steady State Data												SN 025; valve sequence reversed inadvertently
	266	1.50	DM	258	1.00	0.035	1.035	28.6	320	324	219	226	218	5K	1090	1250	87.4	Stable	Single oxid and single fuel circuits
	267	10.0	DM	262	1.00	0.037	1.037	27.0	321	328	234	234	221	5K	1105	1300	85.2	Stable	Same as Run 266
	268	2.30	DM	390	1.29	0.58	1.348	22.2	477	492	281	287	283	7.5K	1265	1470	86.2	Stable	Same as Run 266
	269	9.50	DM	390	1.29	0.057	1.347	22.6	480	492	282	285	280	7.5K	1265	1450	87.4	Stable	Same as Run 266
	270	1.80	DM	279	0.974	0.039	1.013	25.0	334	345	241	245	236	5K	1200	1350	89.0	Stable	Single oxid and single fuel circuit
	271	4.80	DM	280	0.975	0.040	1.015	24.4	336	347	238	251	238	5K	1210	1370	88.2	Stable	Same as Run 270
	272	1.20	DM	280	0.974	0.040	1.014	24.4	-	-	232	242	236	5K	-	-	-	U-87	Single oxid and double fuel circuit
	273	4.50	DM	285	0.974	0.039	1.013	25.0	-	-	250	244	227	5K	-	-	-	U-63	Double oxid and double fuel circuit
	274	4.20	DM	284	0.974	0.039	1.013	25.0	-	-	250	244	231	5K	-	-	-	U-54	Double oxid and single fuel circuit
	275	5.15	DM	373	1.20	0.052	1.252	23.0	-	-	285	285	272	6K	-	-	-	U-95	Same as Run 274
	276	5.36	DM	411	1.33	0.058	1.388	22.9	-	-	286	289	277	7K	-	-	-	U-115	Same as Run 274

(1) SO/IF: impinging oxid, showerhead fuel; SO/SF: showerhead oxid, showerhead fuel; DM: dual manifold.
(2) Unstable tests show predominant frequency noted in chamber pressure.

spikes of up to 60% P_c overpressures. Based on the clearly superior operation of the SO/IF injector, no further testing was performed with the SO/SF injector.

(C) The IO/IF injector, which was designed on the basis of test results with the previous two patterns, was evaluated in a 24-test series. Operation was evaluated over a thrust range from 5 to 42K. At 9K and above, operation was stable and satisfactory in every respect. Low frequency pressure oscillations were encountered from 5 to 8.5K, ranging from $\pm15\%$ P_c and 110 Hz at the 5K level to $\pm4\%$ P_c and 200 Hz at the 8.5K level. Except for these relatively low amplitude oscillations, combustion was smooth and operation was satisfactory. Based on the fact that stable operation had been demonstrated for over 90% of the intended throttling range (Figure 5), the IO/IF injector was selected for Phase II testing. Concurrently with the Phase II program, the dual-manifold IO/IF injector was designed to increase the circuit pressure drops at the low thrust points. One injector module of this configuration was fabricated and tested; stable operation at the 5K and 7.5K level was demonstrated.

C. CLUSTERED SEGMENT TEST PROGRAM

(C) The objective of the clustered segment test program was to evaluate the operation of ten injector segments installed within a common housing simulating the primary combustor configuration of the MIST engine. A photograph of the housing is shown in Figure 6. The test program was initiated on 24 September 1969 and concluded on 3 December 1969, during which period 22 tests were conducted between the 10K and 37.5K operating points. The test data and results for each test are summarized in Table II. At the 10K thrust level, low frequency pressure oscillations of the type encountered in the segment test program were noted, a condition not unexpected. A continuous step throttling test was conducted at the 10K, 12K, and 15K thrust level to establish the lower limit of stable operation. Results showed

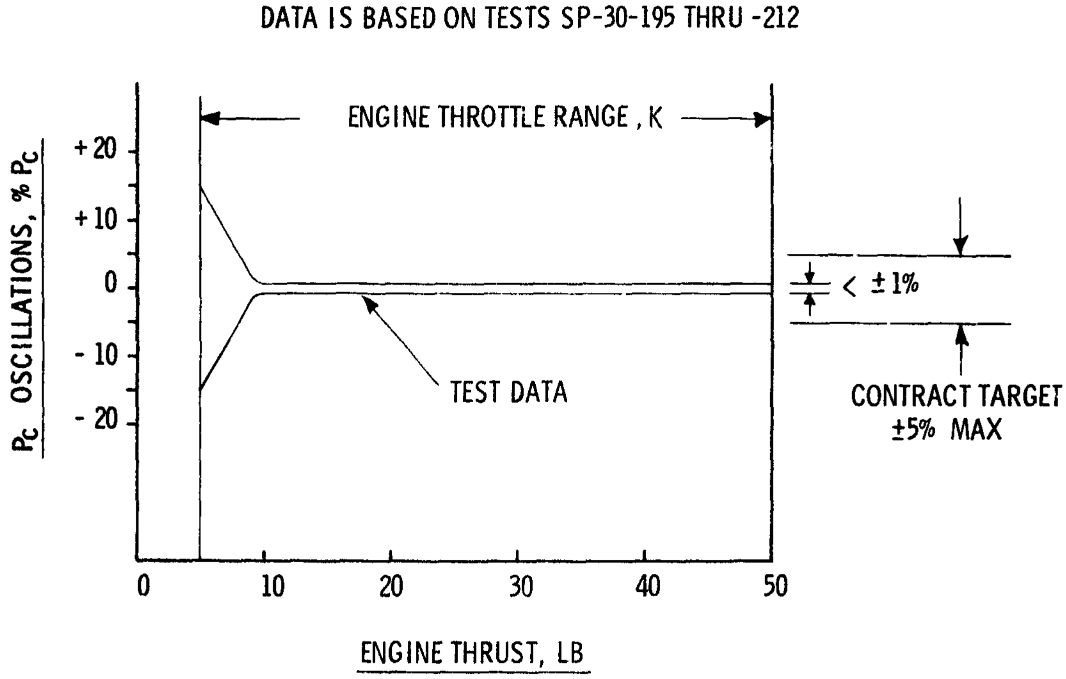


Figure 5. IO/IF Stability Range (U)

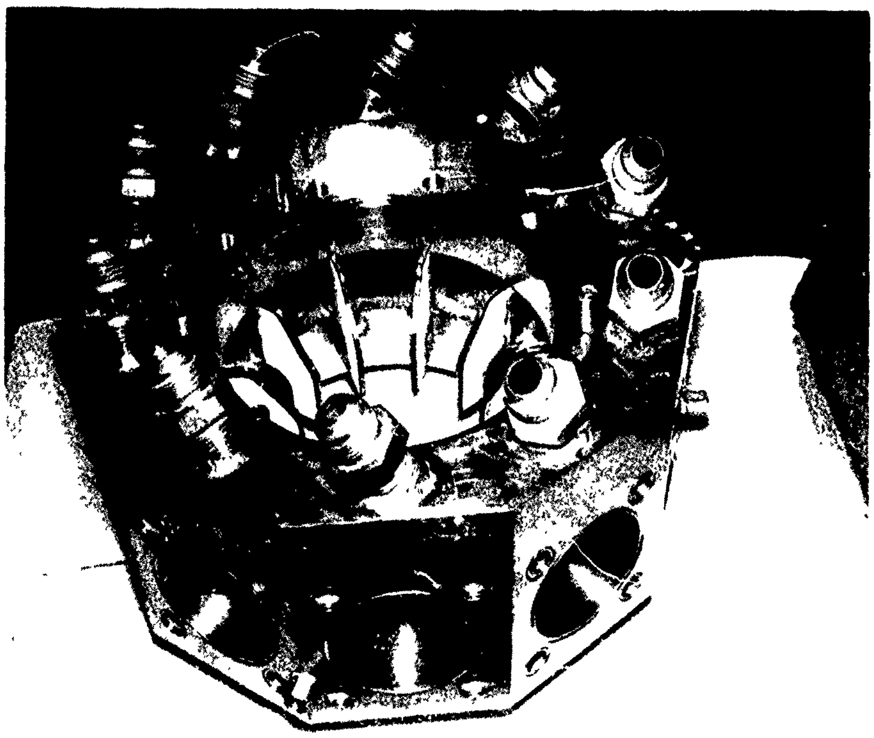


Figure 6. Cluster Injector Housing

TABLE II

TEST DATA SUMMARY - CLUSTER PROGRAM (U)

TEST NO.	DATE	DURATION SEC.	DATA TIME SEC.	NOMINAL THRUST LEVEL lbs_f	CHAMBER PRESSURE PSIA	OXIDIZER FLOW RATE LB/SEC	FUEL FLOW RATE LB/SEC	MIXTURE RATIO O/F	C* FT/SEC	CLUSTERED SEGMENT THERMOCOUPLE DATA TTI-1 °F	TTI-2 °F	TTI-3 °F	TTI-4 °F	TTI-5 °F	TTI-6 °F	TTI-7 °F	TTI-8 °F	TTI-9 °F	TTI-10 °F
1298-D01-OJ-001 (1)	9-24-69	.763	-	-	-			-	-										
-002 (2)	9-24-69	1.012	1.004	22K	1642	37.321	2.035	18.340	1544	(5)			(2)						
-003	9-24-69	3.013	1.53-1.83	22K	1675	31.221	2.279	13.700	1845	1060	840	1010	(2)						
-004	10-27-69	1.007	.907-1.007	22K	1668	40.91	2.09	19.908	1436.3	(5)									
-005	10-28-69	1.064	.964-1.064	22K	1716	38.07	2.18	17.454	1577.4	(5)									
-006	11-10-69	.911	.811-.911	22K	1153	43.65	1.27	34.290	949.7	(5)									
-007	11-10-69	1.107	1.007-1.107	22K	1723	42.16	2.13	19.796	1439.4	(5)									
-008	11-11-69	1.511	1.411-1.511	22K	1692	39.07	2.17	18.020	1518.3	645	657	479	580	620	757	549	788	719	668
-009	11-11-69	2.010	1.910-2.010	22K	1698	40.25	2.14	18.824	1482.4	594	592	451	525	558	708	494	701	649	648
-010	11-12-69	1.252	1.152-1.252	22K	1693	37.84	2.21	17.135	1564.0	680	710	440	580	600	770	600	(6)	790	710
-011	11-12-69	2.000	1.500-2.000	22K	1709	40.35	2.17	18.582	1487.5	610	573	418	603	535	690	492	810	692	(6)
-012	11-12-69	3.007	2.007-3.007	22K	1728	40.84	2.17	18.835	1486.5	605	594	434	601	576	702	484	717	706	654
-013	11-12-69	5.005	4.005-5.005	22K	1722	43.65	2.17	20.617	1392.4	515	508	392	491	504	568	434	587	612	553
-014	11-13-69	9.998	5.0 - 8.0	22K	1716	41.61	2.14	19.408	1451.2	542	602	411	541	604	599	460	707	677	613
-015	11-14-69	2.004	1.504-2.004	10K	689	18.63	.87	21.314	1307.4	317	360	314	371	340	327	322	371	366	355
-016	11-17-69	2.999	2.95 (4)	15K	1089	26.8	1.40	19.2	1430.0	536	640	390	615	615	700	410	730	750	640
-017	11-19-69	3.005	2.00-3.005	15K	1079	30.37	1.32	23.010	1259.4	358	389	338	387	420	(6)	333	434	450	420
-018	11-19-69	9.298	8.298-9.298	15K	1092	28.19	1.36	20.721	1367.5	463	493	358	579	643	446	361	588	-	627
-019	12-02-69	.915	.915	25K	1240	-	-	(3)	(3)	(5)									
-020	12-02-69	3.002	1.500-3.000	25K	2004	45.92	2.60	17.758	1536.7	716	770	454	660	570	805	541	831	681	805
-021	12-02-69	1.402	1.302-1.402	37.5K	3347	56.68	4.61	12.299	2020.9	(5)									
-022	12-03-69	1.809	1.709-1.809	37K	3267	57.84	4.46	12.963	1940.3	1170	1123	954	1094	943	1271	969	1332	(6)	(6)

(1) Transient Test, No Steady State Data
(2) Only Three Thermocouples Employed
(3) Loss of Oxidizer Flowmeter Prevented Receipt of this Data
(4) Third step data summarized
(5) Test duration too short for valid temperature data
(6) Invalid Thermocouple

II, C, Clustered Segment Test Program (cont.)

operation at the 12K level to be marginally stable, with completely smooth operation occurring at the 15K level. Operation at the 25K thrust level was excellent, with no anomalies occurring. The highest equivalent thrust level to which the assembly was tested was 37.5K. At this thrust minor erosion occurred in one of the ten combustion chambers; a posttest evaluation determined that the injector segment feeding the damaged portion of the chamber had an uneven mixture ratio profile across its face, which produced a localized area of hot gas that caused the erosion. Limitations of program funds precluded further testing in the program.

(C) Primary combustor performance was excellent at all thrust levels; in the clustered configuration, c* values were in close agreement with those obtained in the segment program, usually slightly higher. Also, combustion was very smooth at all levels above the "chugging" threshold, with chamber pressure oscillations being $\pm$ 1% of average chamber pressure.

III. CONCLUSIONS

(C) 1. The technology for a throttling primary injector using the HIPERTHIN injector concept was demonstrated.

(C) 2. The HIPERTHIN injector demonstrated excellent performance characteristics in a very short chamber length (3 inches). The delivered performance at all thrust levels was sufficiently high to provide the required energy for turbopump drive.

(C) 3. Three injector designs were identified as being suitable for use in an advanced storable propellant staged-combustion space engine such as the MIST engine: (a) The SO/IF injector is suitable for an engine operating at 2800 psia secondary chamber pressure and a required throttle ratio of 3:1;

III, Conclusions (cont.)

(b) The IO/IF injector is suitable for an engine operating at 2400 psia secondary chamber pressure and a required throttle ratio of 5:1; (c) the IO/IF dual manifold injector will provide 10:1 throttle capability at a secondary chamber pressure of 2400 psia. This injector does require throttling valves in both the fuel and oxidizer circuits, a condition not required with the other two injectors.

(C) 4. Low frequency "chugging" instability at the low throttle range was the only major technical problem encountered during the program. The low frequency characteristics dictated the classification of injector operating ranges as listed in Item 3, above. In the stable operating range, combustion is very smooth, with chamber pressure oscillations averaging $\pm 1\%$ of the average value. Pulse testing demonstrated the dynamic stability of the primary injector. In no case did the pulse cause a combustion instability.

(U) 5. The basic injector design was shown to have excellent durability characteristics. Throughout the entire program, which encompassed 176 segment tests and 22 cluster tests, no structural failure or distortion occurred with any injector. During the segment program one injector was fired 87 times for a cumulative duration of over 200 seconds.

(C) 6. The planned throttling demonstration over the full thrust range (10K to 50K) with the clustered segment hardware was not made because of the hardware damage incurred during a test at the 37.5K level and because the funds remaining were insufficient to repair the hardware and continue testing. The cause of the damage was attributed to a mixture ratio maldistribution in one of the injectors. The adverse mixture ratio profile across its face resulted in a hot streak. Replacement of this injector with one having a proper mixture ratio profile should resolve the problem. Posttest flow testing of several injectors revealed that minor maldistribution was present in all injectors, although not to the extent of that of the injector which caused the problem. This could have resulted from either contamination or the net tolerance effects of the platelet stack. Both of these potential causes and means for their prevention should be thoroughly evaluated in any future design.

IV. PRIMARY COMBUSTOR DESIGN

A. DESIGN CRITERIA AND REQUIREMENTS

(C) The primary injector design criteria and requirements were established by the MIST engine design and operating specification, discussed fully in the Appendix. Engine-imposed injector design criteria included operating conditions such as mixture ratios, flow rates, and pressures, as well as envelope constraints in diameter, height, thickness, and interface. The major primary combustor parameters, as defined from the engine power balance, are shown in Figures 2 and 7 over the operating thrust range. Figure 2 is for an engine operating at 2,800 psia chamber pressure, while Figure 7 is for one operating at 2,400 psia. Injectors compatible with both engine balance points were evaluated in the test program.

(C) The basic primary combustor assembly configuration was established by engine packaging considerations. An annular injector configuration flowing radially inward was shown to integrate best with the basic engine concept to produce a minimum-weight, neatly packaged engine design. The primary combustor gases turn 90° downward prior to entering the turbine, which is attached to the main axial shaft (see Figure 3). A design study in which injector diameter and height were evaluated with respect to combustion volume and shape, engine weight, and overall engine packaging resulted in the selection of a 7-in. inside diameter injector having a height of 1-3/4 in. The combustion chamber is relatively small, having a length of 3.00 in. (along the flow center line) and a total volume of 45.8 $in.^3$. This design was analyzed to determine its expected performance by using a propellant vaporization model that has been used successfully in analyzing main thrust chamber performance. Results of this analysis are presented below.

(C) The primary combustion process proceeds as follows: First, all the fuel is burned with an amount of oxidizer required for near-complete combustion. The excess oxidizer is then vaporized by heat transfer from

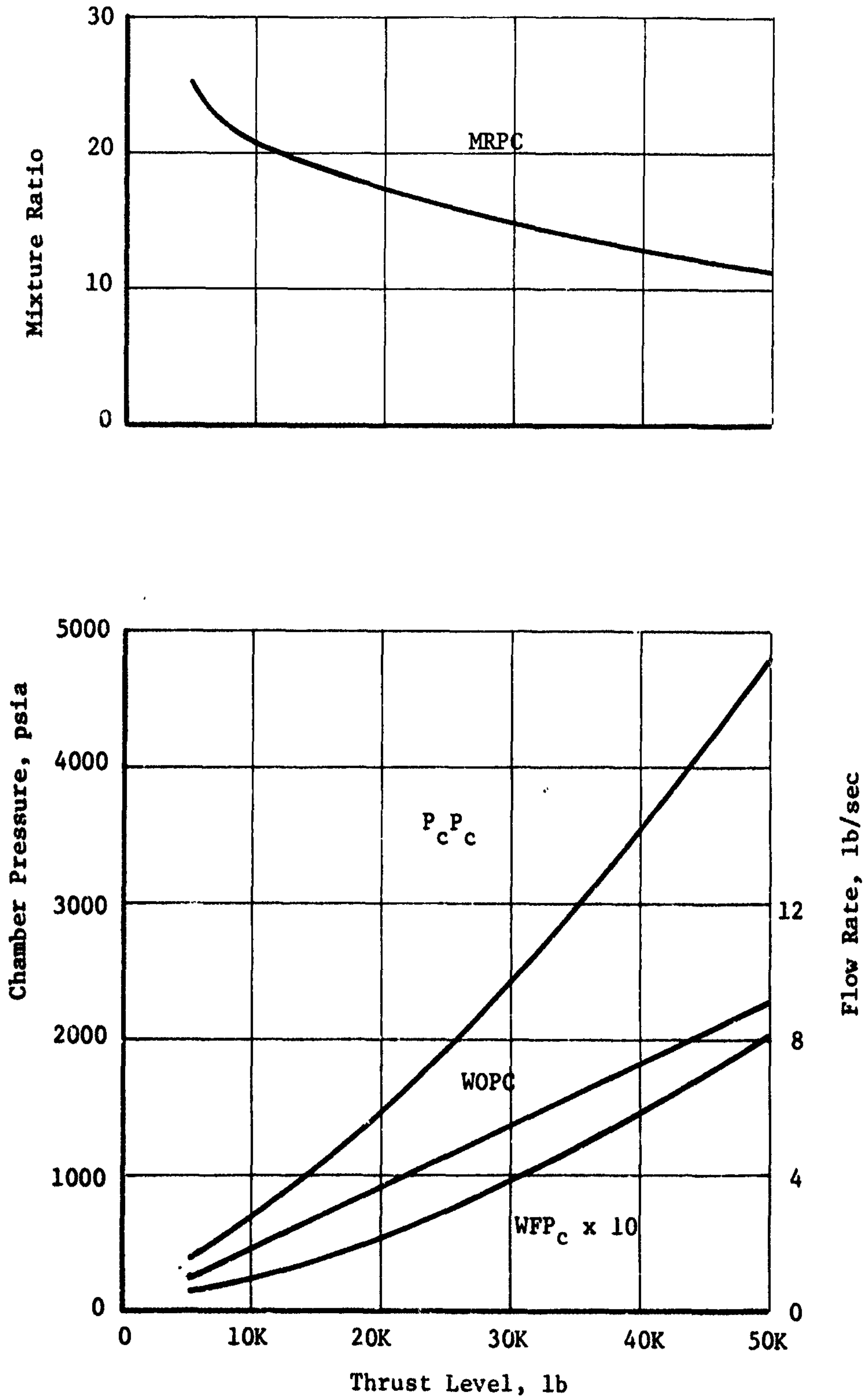


Figure 7. Primary Combustor Operating Parameter (2400 P_c Model)(U)

the combustion products. The model predicts that the combustion part of the process is essentially completed by the time the gases exit the primary combustor; however, the oxidizer vaporization is not completed. Therefore, at the turbine inlet, the combustion products consist of a mixture of gases at a temperature corresponding to the mixture ratio of the gasified products, and unvaporized liquid oxidizer. The temperature of the gasified product is shown as a function of the mean path distance from the injector face in Figure 8. The equilibrium temperature is also shown. As the oxidizer vaporization progresses and the combustion gas temperature is reduced, the heat flux to the remaining oxidizer is decreased, and further oxidizer vaporization is obtained at a much slower rate. (The possible effect of residual oxidizer droplet impingement at the turbine inlet may result in droplet shattering, which could significantly increase droplet surface area available for vaporization. The resultant effect on gas temperature through the stator is indicated by the dashed lines in Figure 8.) The resultant characteristic curve shows that, after the first inch of chamber length, the vaporization rate is very low and significant changes in length are required to cause much change in gas temperature. Various injection patterns tend to locate the point at which the knee of the curve occurs, but have little effect downstream of the knee. Therefore, the amount of unvaporized oxidizer is primarily a function of mixture ratio, with pattern design and length being of secondary importance only to the extent that the length must be sufficient to assure operation below the knee of the curve. The effect of incomplete vaporization on predicted c* efficiency at various thrust levels is shown in Figure 9. The reduced primary combustor efficiency at low thrust is compensated for by balancing to a lower mixture ratio and increasing gas temperature so that the proper power requirement is met.

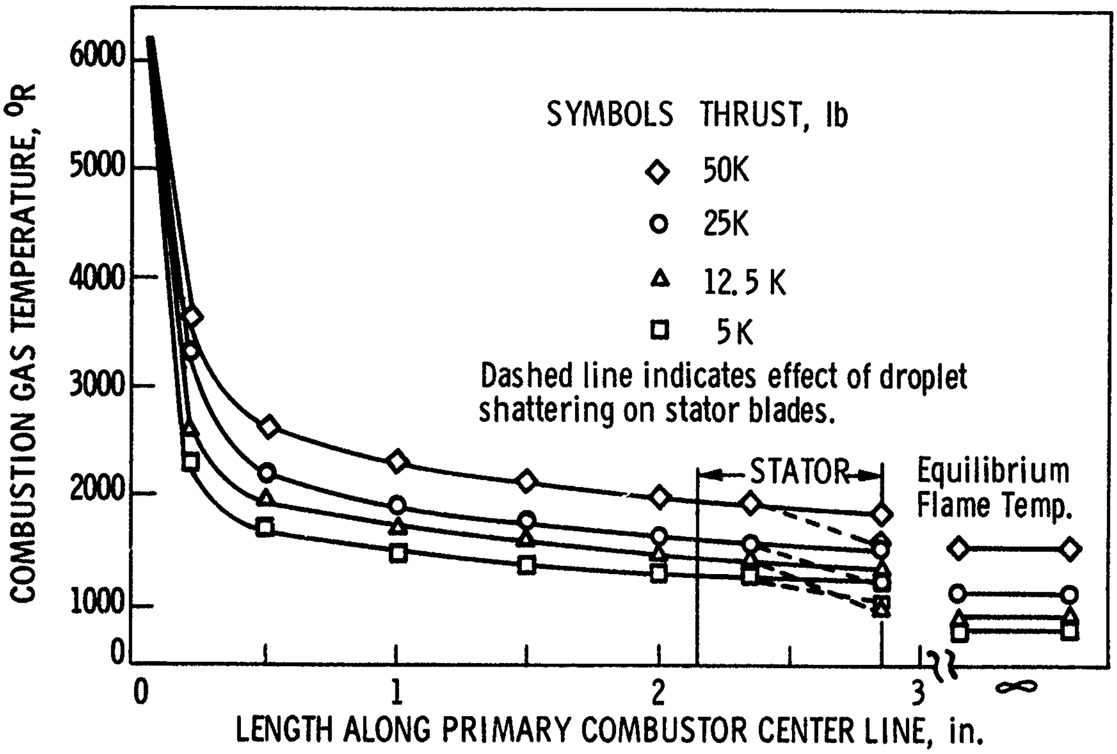


Figure 8. Gas Temperature vs Distance from Injector

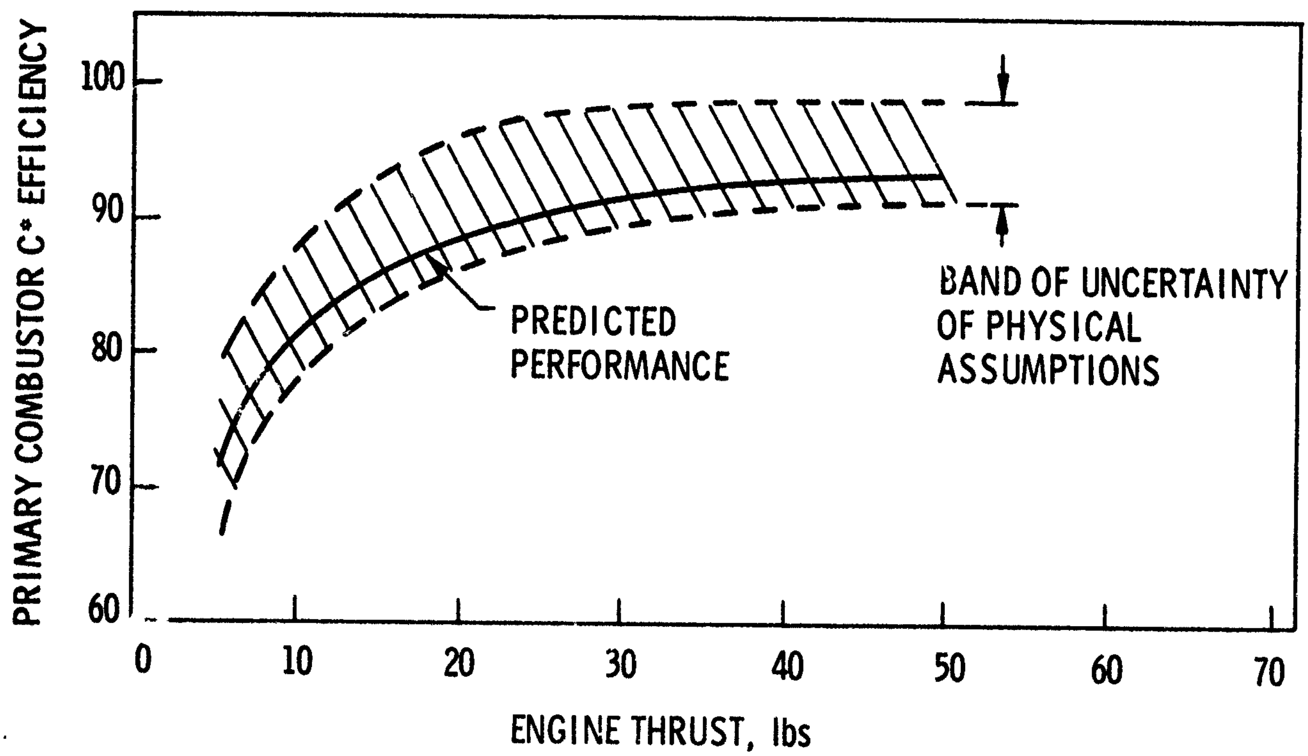


Figure 9. Predicted c* Efficiency vs Thrust (U)

B. INJECTOR DESIGN

1. Basic Design Approach

(U) Three basic injector configurations were studied in detail during the design study portion of the program. All used the HIPERTHIN injector concept, as dictated by the contract work statement. The first design, shown in Figure 10, was designated the annular ring injector. In this concept, disc-shaped platelets are stacked in the plane normal to propellant flow. The injector consists of multiple platelet sets that are stacked and then brazed into the injector body. Each platelet set consists of three platelets, one fuel platelet with an oxidizer platelet on either side. The resulting assembly is a one-piece unit with uniform propellant injection around the entire engine circumference.

(U) The second design considered, designated the segmented injector, is shown in Figure 11. This design consists of ten identical platelet segments that are brazed into a decagonal ring structure. The platelets of each segment are stacked in a plane parallel to propellant injection and sandwiched between two end plates. Individual segments are then individually brazed, after which they are machined to final dimensions. The completed segments are assembled onto the injector body (which contains the fuel manifold and is identical in design to that of the annular injector) and the entire assembly is brazed together in a second braze cycle. In this same cycle, the end plates of the individual segments are brazed together.

(U) The third injector approach investigated, called the modular injector, is similar to the segmented injector except that the individual injector segments are contained in cylindrical cartridges that are welded directly into the engine housing (see Figure 3 and Figure A-1 of the Appendix). An individual injector module is shown in Figure 12. Two metal piston rings (in one groove) provide a low leak path seal between the oxidizer manifold and the combustion chamber; the fuel manifold is isolated from the oxidizer

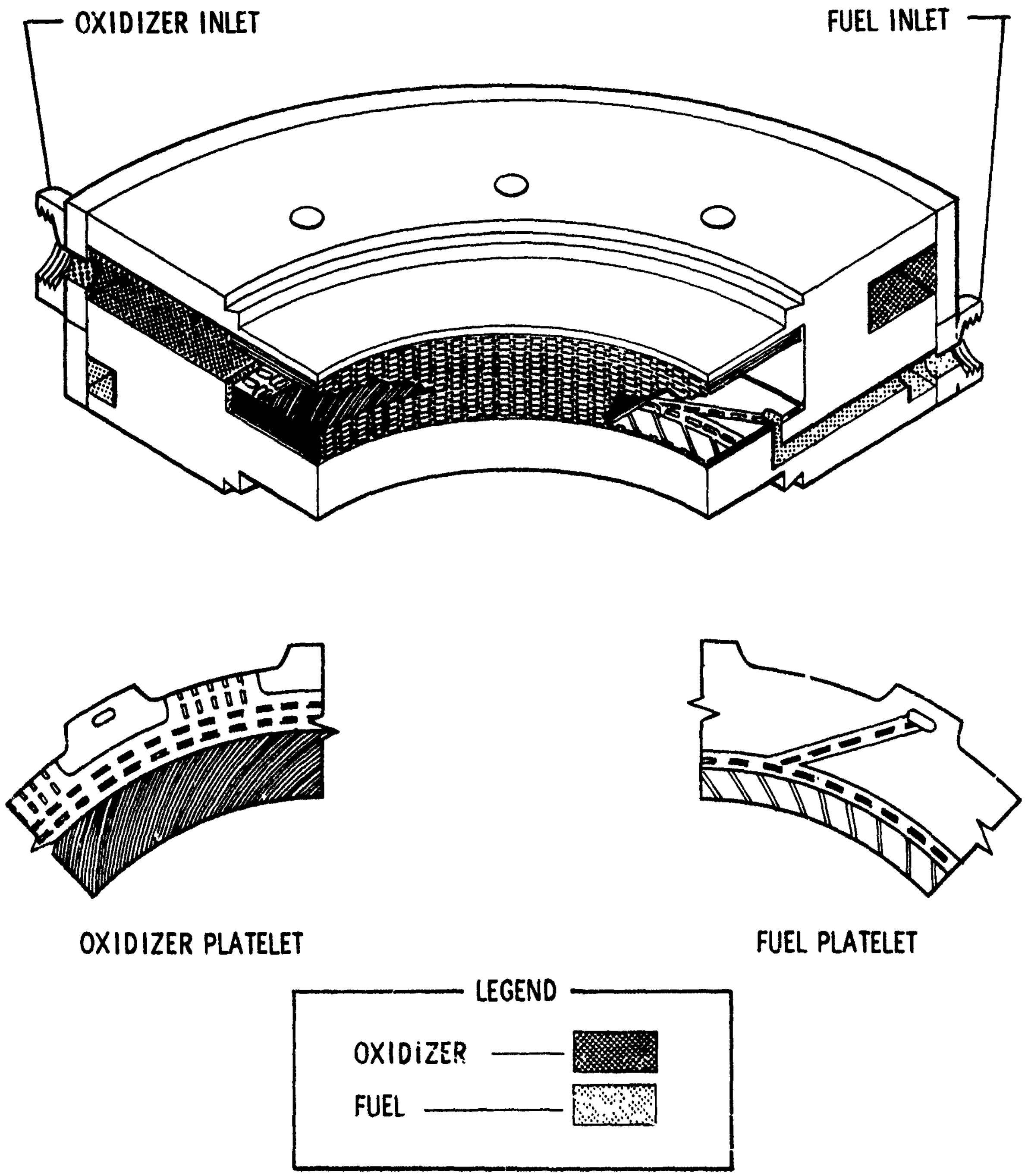


Figure 10. Annular Ring Injector

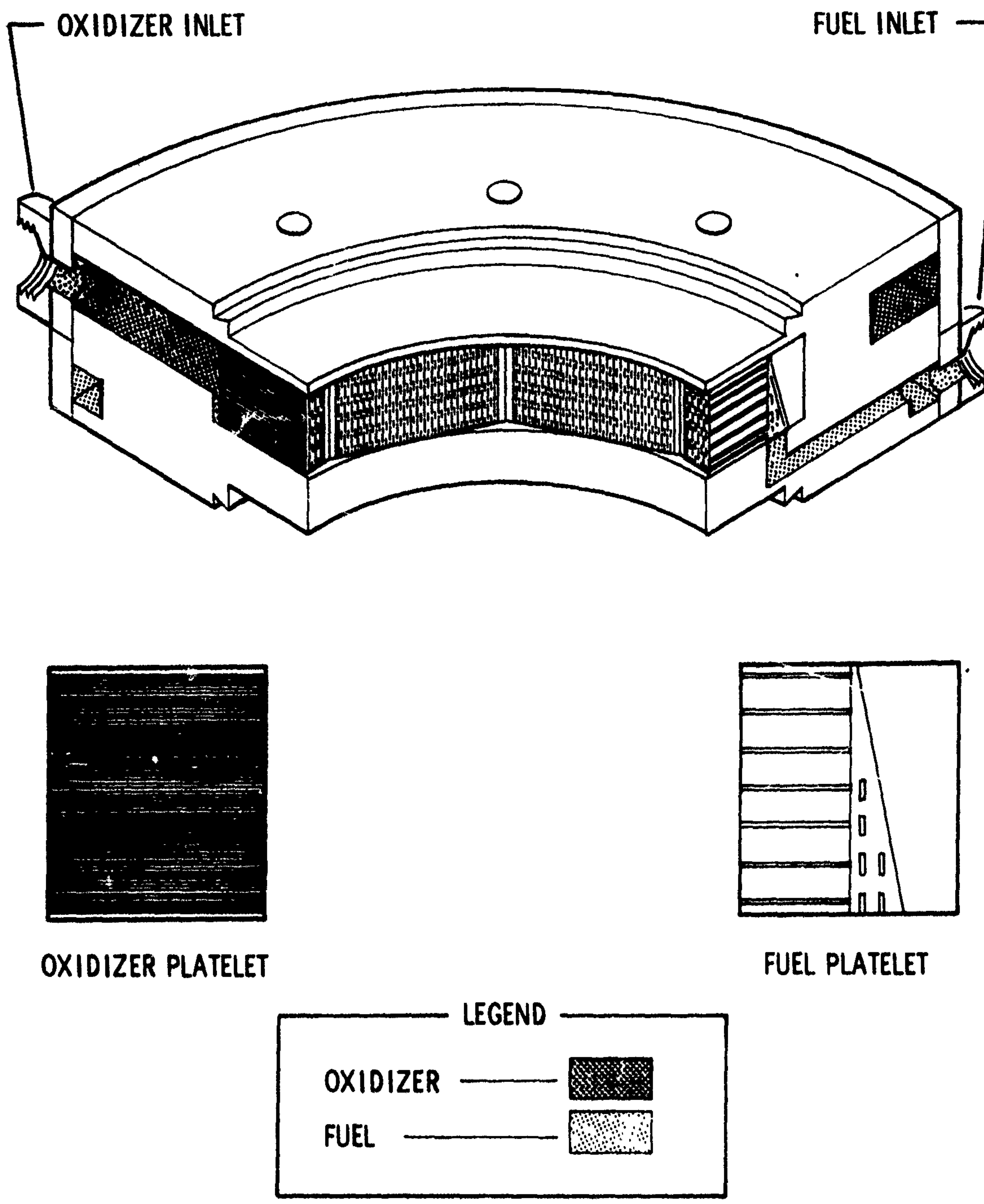


Figure 11. Segmented Injector

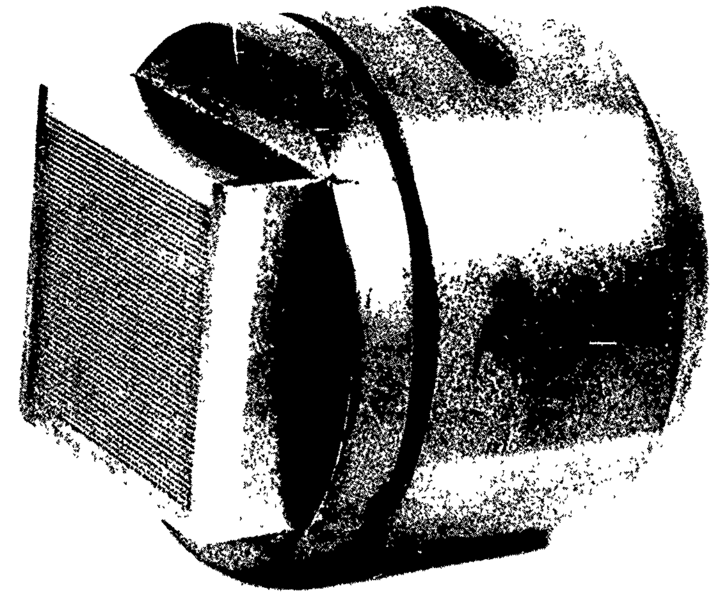


Figure 12. Modular Injector

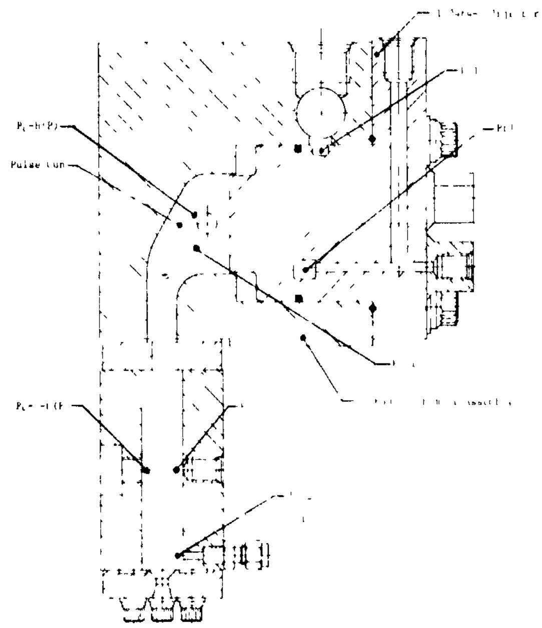


Figure 13. Segment Assembly

manifold by the weldment of the module to the housing. The fuel is sealed to the outside by a cap welded to the housing, which also forms the back of the fuel manifold (see Figure 3).

(U) Each of the candidate injector designs has advantages relative to the other; all were considered capable of meeting the requirements of this program. The annular injector requires fewer platelets, and has greater pattern flexibility in that it contains an uninterrupted 360° surface (e.g., the pattern shown in Figure 10 could not be used in the other designs without significant edge effects). Also the entire injector assembly requires only one braze cycle. A disadvantage with this concept is the size of platelet required (approximately 11 in. O.D.) which is substantially larger than the platelet size normally used for injectors; this could present a state-of-the-art problem in fabrication techniques. Furthermore, since the injector is a one-piece unit, a fabrication problem could render the entire part, which represents a sizable cost investment, unusable. By comparison, the segmented injector uses platelets within the state-of-the-art size, involves multiple platelet components which are fabricated separately, and provides the flexibility of replacement of one or more segments if required by fabrication or test problems (e.g., an intropropellant task developing in one segment). This replacement would be accomplished by machining out the bad segment(s) and replacing it with a new one. Disadvantages of this concept are the relative pattern inflexibility and the requirement of two braze cycles in the fabrication process. The modular injector, the selected design concept, has the relative advantages of the segmented injector together with a significant additional advantage. This injector is the most cost effective during development; a large portion of the development can be accomplished with single modules using a low cost test facility. Furthermore, since the cost of a single module is substantially lower than that of a full injector, more patterns can be evaluated for the same total cost.

2. Injector Module Design

(U) Four different HIPERTHIN injector patterns were designed, fabricated, and test-evaluated during the Phase I program. The first two patterns were designed and evaluated concurrently during the first part of the program, while the third and fourth patterns were iterations based upon test results. All injectors were of the same size and geometrical shape, having a rectangular face 1.75 in. in height by 2.0 in. wide. The injectors are of flightweight configuration except for an added flange to facilitate bolt-on capability for development ease. A typical injector is shown in Figure 4. Oxidizer enters the injector through the slot on the cylindrical portion of the injector; fuel enters through the port on top of the injector flange, passes down through the flange into a slot located below the platelet stack and normal to the injector face. The oxidizer is sealed from the combustion chamber by metal piston rings identical to those used in the flightweight engine design. The external oxidizer seal is a metal O-ring which is replaced by a weldment on the engine design. A cross section assembly of the injector installed in the test housing is shown in Figure 13. Each of the four injector patterns is discussed in the following paragraphs. Design parameters are summarized in Table III.

a. Showerhead Oxidizer - Showerhead Fuel Pattern (SO/SF)

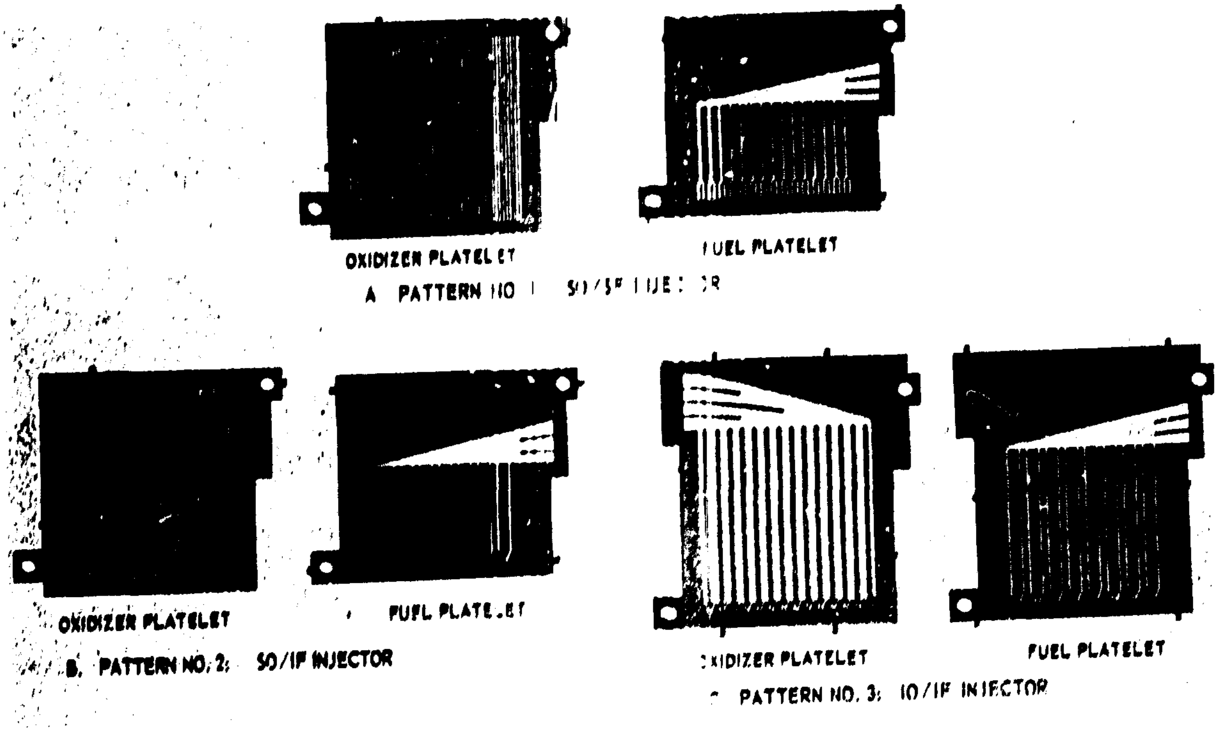
(U) This pattern has showerhead orifices in both the oxidizer and fuel circuits. The metering platelets used are shown in Figure 14. As with all the injector patterns, the platelet stackup is made by alternating in sequence four sets of oxidizer metering and separator platelets with one set of fuel metering and separator platelets. The sequence is repeated beginning and ending with oxidizer platelet sets until 42 fuel platelet sets have been installed. The total number of injection orifices in the pattern

TABLE III

INJECTOR PATTERN DESIGN DATA

Injector Type	Feed Channel Dimensions (inches) Oxid	Feed Channel Dimensions (inches) Fuel	Channel Length (inches) Oxid	Channel Length (inches) Fuel	Orifice Dimensions (inches) Oxid	Orifice Dimensions (inches) Fuel	Injection Velocity (ft/sec) 5K Flow Rates Oxid Circuit	Injection Velocity (ft/sec) 5K Flow Rates Fuel Circuit	Injection Velocity (ft/sec) 50K Flow Rates Oxid Circuit	Injection Velocity (ft/sec) 50K Flow Rates Fuel Circuit
SO/SF	.002x.015	.002x.015	1.5	.75	.002x.015	.002x.015	6.2	2.1	59	54.7
SO/IF	.002x.015	.002x.015	1.5	.75	.002x.015	.002x.013	6.2	2.8	59	73
IO/IF	.002x.030	.002x.015	1.46	1.44	.002x.010	.002x.013	8.3	2.8	79	73
IO/IF (Modified)	.002x.030	.002x.015	1.46	1.32	.002x.010	.002x.013	15.6	2.8	149	73
Dual Manifold	.002x.030	.002x.020 Alt Plate	1.46	1.72	.002x.010	.002x.013 Alt Plate	31.2 (1)	5.6 (1)	149	73
		.002x.015	1.46	1.32		.002x.013				

(1) Velocities shown are for single manifold operation. Velocities using both manifolds are the same as IO/IF (Modified) injector.



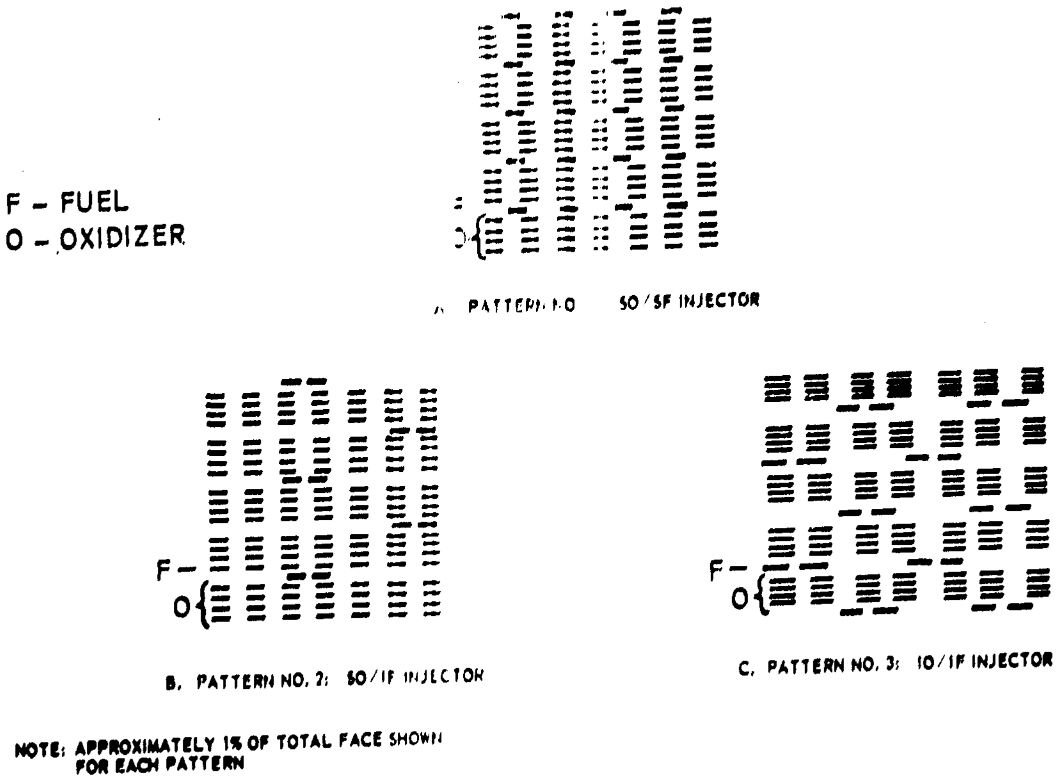


Figure 14. Metering Platelets and Face Pattern Schematics

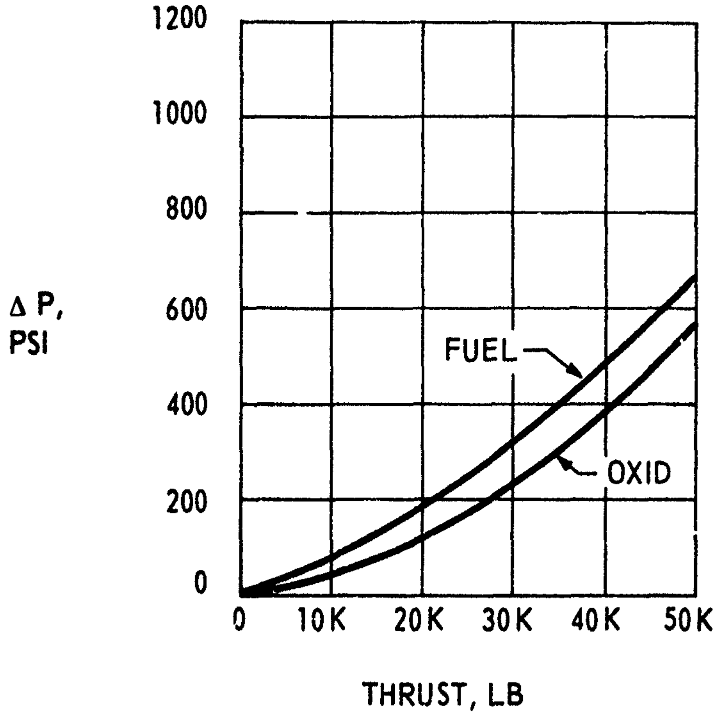
are 8600 oxidizer and 1260 fuel. A schematic of the resulting face pattern is also shown in Figure 14. Circuit pressure drops as a function of thrust level are shown in Figure 15.

b. Showerhead Oxidizer - Impinging Fuel Pattern (SO/IF)

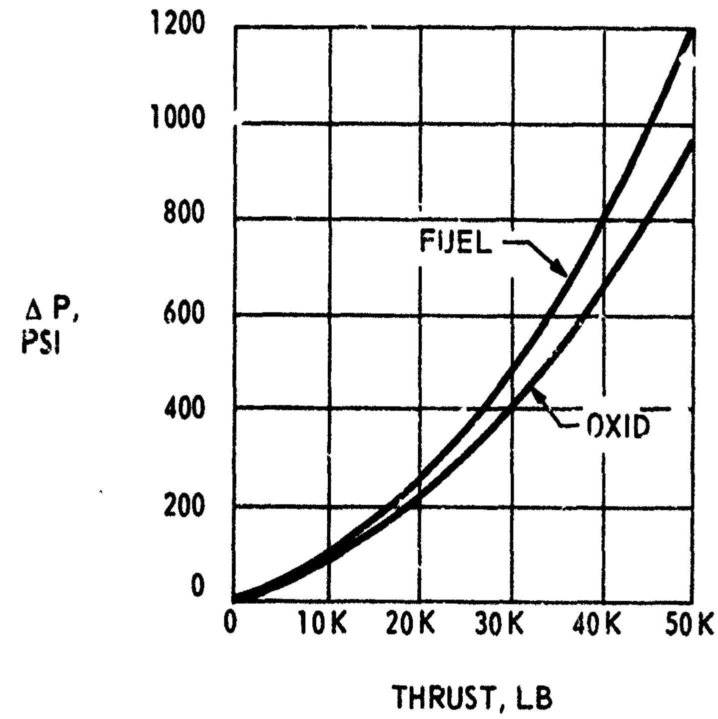
(U) This pattern uses the same showerhead oxidizer platelets as the SO/SF injector, but the fuel metering platelets incorporate impinging fuel orifices as shown in Figure 14. The total number of injection orifices in the pattern are 8600 oxidizer and 630 fuel. The 630 fuel orifices are comprised of alternating fuel metering platelets containing 7 and 8 impinging orifice pairs. The design circuit pressure drops are the same as those of the SO/SF (Figure 15).

c. Impinging Oxidizer - Impinging Fuel (IO/IF)

(C) Data obtained from tests conducted on the SO/SF and SO/IF injectors disclosed that: (1) the SO/IF injector produced far smoother combustion than the SO/SF injector, (2) higher circuit pressure drops were required to prevent low frequency oscillations from occurring at the lower thrust levels, and (3) the chamber walls were grossly overcooled. Based on this information, the IO/IF orifice pattern was designed. The oxidizer pattern was converted from 50 showerheads to 14 impinging pairs (because of the relatively smooth operation of the impinging fuel pattern of the SO/IF injector), and the pressure drop in both circuits was substantially increased. The circuit pressure drops are shown in Figure 15. The additional pressure drop was obtained by lengthening the flow passages in the fuel metering platelet, and by redesigning the oxidizer metering platelet to incorporate impinging orifices at the face plane, similar to that of the fuel metering platelet. The platelets and face pattern are shown in Figure 14.



A. SO/SF AND SO/IF INJECTORS



B. IO/IF INJECTOR

Figure 15. Design Pressure Drop vs Thrust

IV, B, Injector Design (cont.)

(U) To reduce the overcooled chamber condition, the stacking sequence was revised and an additional fuel platelet set was added. In this design the beginning and ending platelet sets consist of two oxidizer sets instead of the previous four. The remaining sequence of four oxidizer metering and separator platelet sets alternating with one fuel metering and separator platelet set continues until 43 fuel platelet sets have been installed. The pattern contains 4816 oxidizer and 646 fuel orifices.

d. Dual Manifold IO/IF Injector

(C) Test data with the IO/IF injector showed that the unit was within the contract specifications from the 9K thrust level up to 45K thrust. However, between 5K and 9K low frequency chamber pressure oscillations were noted in increasing amplitude from $\pm$ 4% P_c at the 8.5K thrust level to $\pm$ 15% P_c at the 5K thrust level. These oscillations were identified as a classic chugging mode, resulting from insufficient injector pressure drop at the low thrust levels. To stabilize operation at throttled conditions, a dual-manifold injector was designed and test-evaluated. In this design, two fuel and two oxidizer circuits were incorporated; during engine operation at the low thrust levels one set of circuits would be valved closed, thus forcing all the propellant through the remaining circuits, increasing the circuit pressure drops.

(U) The 8-pair fuel metering platelets were redesigned to increase the channel length, thereby facilitating a separate fuel plenum beneath the assembled platelet stack. The new fuel plenum was fed through the original fuel inlet at the top of the injector flange. The alternating 7-pair platelet plenum was plumbed through a thin wall tube and fed through the injector fuel pressure port (P_{fJ}). The oxidizer platelets were redesigned so that the plenums of one-half the platelets opened up during machining 0.080 inch prior to the remaining half. The two types of platelets were

alternated on assembly to obtain symmetry of injection. After testing the single-manifold modules, the oxidizer circuit was machined the remaining 0.080 inch to open the second oxidizer circuit. The remainder of the test program was conducted with both oxidizer circuits open.

(U) The single-manifold mode contained 2408 oxidizer orifices and 352 fuel orifices. The dual manifold injector components are identical to the IO/IF injector except for the displacement of the fuel plenum on the 8-pair platelet. The rise in pressure drop due to the displaced plenum was balanced by enlarging the channel dimension feeding the orifices. The design variation between the single circuit injector and the dual manifold injector is shown schematically in Figure 16. The face pattern schematic depicted in the figure is identical for both injectors.

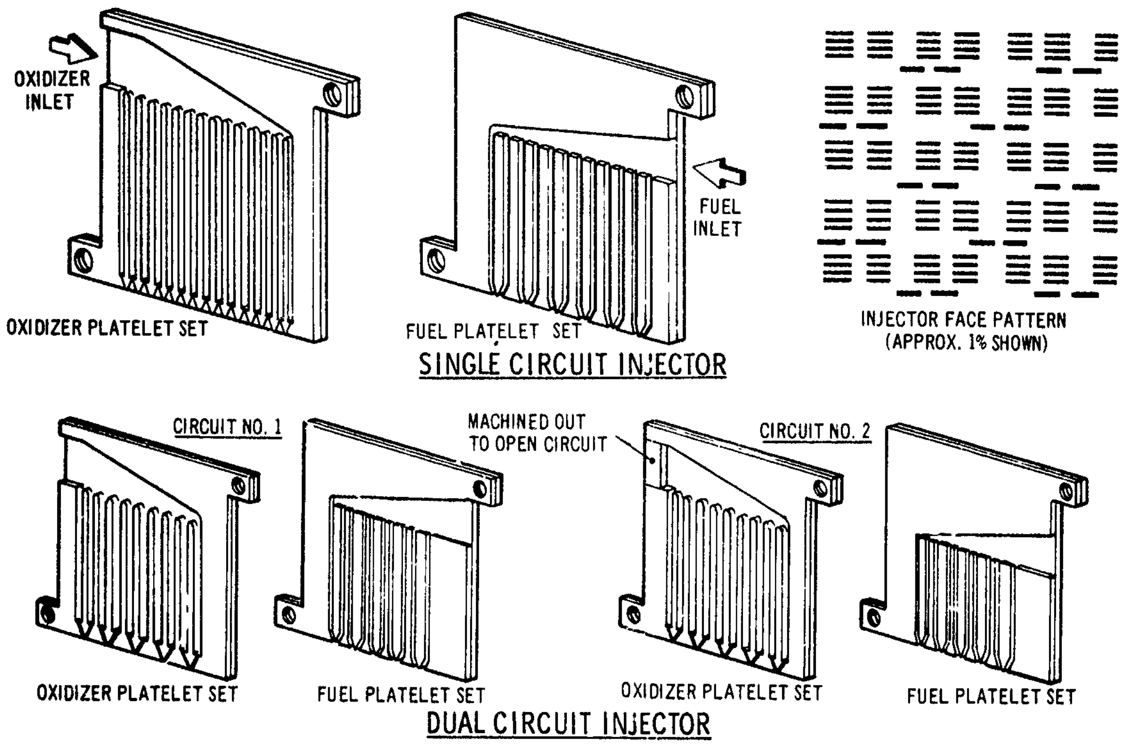


Figure 16. Comparison of Single-Manifold and Dual Manifold Metering Platelets

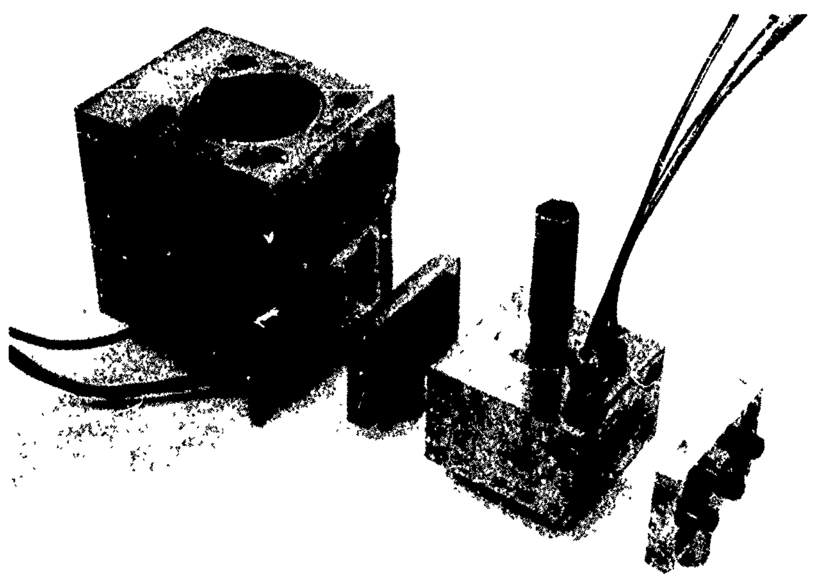


Figure 17. Combustion Chamber Housing Assembly

C. COMBUSTION CHAMBER DESIGN

(U) The combustion chamber designs used for the injector evaluations are discussed in this section. Two basic configurations were designed, one with a single combustion chamber for use in the segment test program, and one with all ten segments arranged as in the engine for the clustered segment test program.

1. Segment Program Combustor

(U) The combustion chamber housing, shown in Figures 13 and 17, is designed with two mirror-image halves into which the internal combustion contour is machined prior to brazing the halves together. It is fabricated from CRES 347 material. Chromel-alumel thermocouples are brazed integrally into the joint to measure gas-side wall temperatures down the chamber wall. The segment housing contour differs slightly from the clustered housing, which precisely matches the engine configuration. The engine configuration consists of 10 segments located circumferentially about the engine centerline; this results in the chamber walls converging at an 18° half-angle as they move towards the center of the engine. The combustion chamber (downstream of the injector interface) makes a 90° turn and terminates at the turbine stator vanes in a curved, trapezoidal shape. The segment housing, for ease of fabrication, was designed with parallel walls and terminates in a rectangular shape. This difference results in a volume of 5.50 $in.^3$ for the segment housing, compared to 4.58 $in.^3$ for a one-tenth segment of the engine configuration. The L′ (mean distance from the injector face to the turbine simulator plate) was maintained at the engine dimension of 3.00 in.

(U) A close-tolerance cylindrical interface is provided to feed oxidizer from the chamber housing into the injector. This interface is sealed

to the outside by a metal "O" ring, and sealed to the combustion zone by two piston rings. Instrumentation capability, in addition to the wall profile thermocouples, includes ports for a Photocon 307 high frequency pressure transducer, a Taber low frequency pressure transducer, and an AGC Model V pulse generator. Instrumentation locations are shown in Figure 13.

(U) A sonic throat consisting of a multihole converging - diverging nozzle fabricated from a 0.5-in.-thick stainless steel plate is attached to the aft end of the combustion chamber housing. A photo of the sonic nozzle plate is included in Figure 17. The design discharge coefficient of the nozzle (C_D) used in the test program to calculate c* performance was 0.75.

(U) In the latter portion of the segment test program, a chamber extension attached to the main chamber housing was evaluated. This extension, shown in Figure 17, was designed to provide the proportional segment volume and length between the turbine and secondary injector, and thus more closely simulate the engine configuration. The extension volume is 5.9 in.^{3}, with a chamber length of 3.5 in. A turbine simulator plate, fabricated from a 0.5-in.-thick metal plate with three drilled holes, was installed between the combustion chamber and the extension. The turbine simulator plate is shown in Figure 17. The connotation "turbine simulator" is a misnomer in the sense that the plate does not extract work from the primary gas, and therefore cannot effect the same pressure drop on the test hardware that the turbine does on the engine. However, both the turbine simulator plate and the turbine are subsonic devices and are placed in the same relative location, and do provide acoustic similarity.

2. Clustered Segment Program Combustor

(U) The clustered segment combustor is composed of an assembly of three parts; the injector housing, the forward combustion chamber housing,

and the aft combustion chamber housing. All are fabricated from CRES 347 material. A schematic of the assembled unit is shown in Figure 18. Photographs of the component parts are shown in Figure 19. The combustion chamber is composed of the forward housing which forms the inner chamber contour, and the aft housing, which forms the outer chamber contour. The forward housing includes a high frequency Photocon port, standard Taber port, a pulse gun port, and mounting holes for the turbine simulator orifice. The injector housing includes the interfaces for the ten injector assemblies and the oxidizer inlet ports for each injector. The injectors are inserted into cylindrical ports machined radially from the outside of the housing ring. The injectors are sealed on the cylindrical portion to isolate the oxidizer circuits from the combustion chamber. Metal O-rings seal the oxidizer circuit on the outside. At the base of the cylindrical section a transition is made to a rectangular window. This window forms the interface for the rectangular portion of the injector modules. Conoseal joints are used to interface the forward and aft chamber housings.

(U) The combustion chamber volume is separated into ten equal parts by means of baffles which extend from the injector housing down to the turbine simulator plate. The baffles are 1/8-in. thick and are indexed by means of slots in the chamber housing (see Figure 19). During the test program two design modifications were made on the baffle assembly. The first modification was implemented to eliminate the gap between the baffle and the injector housing for the purpose of further isolating adjacent combustion compartments. Slots were designed into the injector housing and the baffle plates were extended into the slots. The second design modification was incorporated when the injector housing eroded during a test at the baffle interface. To eliminate the discontinuity between the housing and baffle, the interface was redesigned to provide a welded joint instead of the slotted one. Figure 19 shows the final configuration.

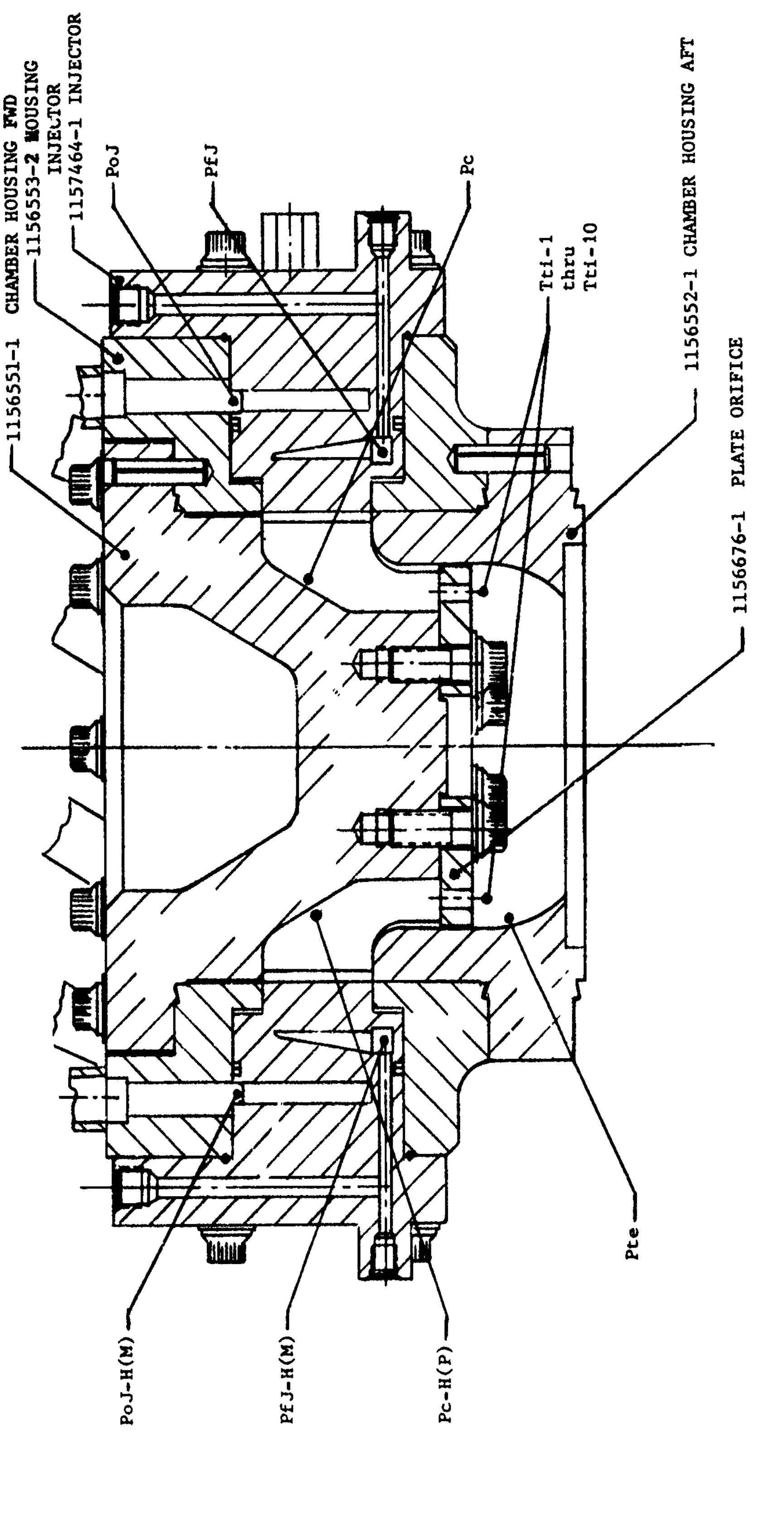


Figure 18. Cluster Assembly

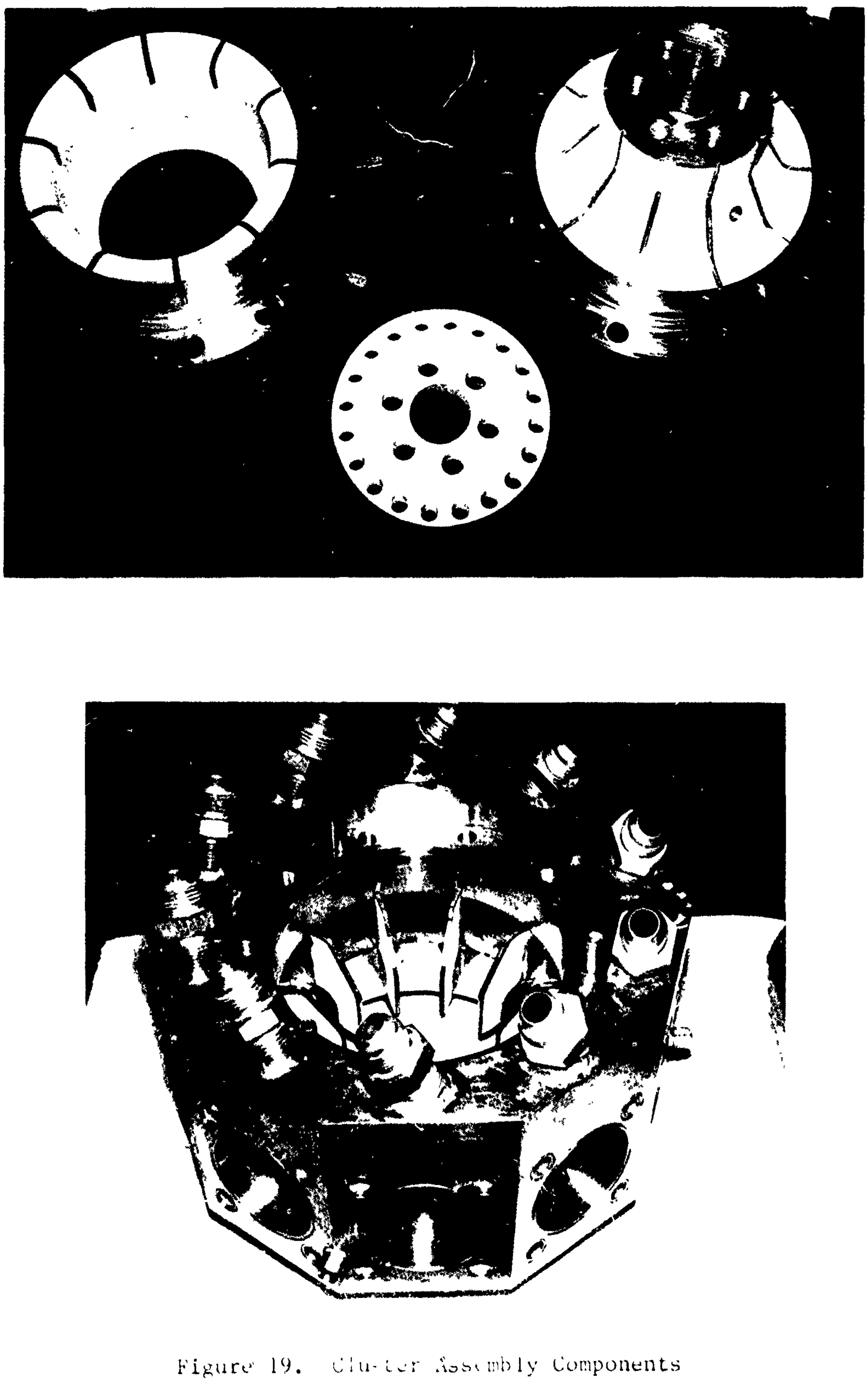


Figure 19. Cluster Assembly Components

V. COMPONENT FABRICATION

(U) The major items of hardware fabricated during the program, together with part numbers and number of each part built are shown in Table IV. No significant fabrication problems were encountered during the program, although two injector design deficiencies were discovered during the early phase of fabrication. Fabrication of the first injector disclosed that the fuel platelet plenum was not adequately supported and sagged during the braze cycle. Fabrication of the second injector pointed out a marginal tolerance condition between the fuel manifold and the fuel plenums of the injector platelets. This condition permitted braze alloy to enter the fuel plenum during the second braze cycle. These problems were corrected on subsequent units.

(U) The fabrication of the injector consists of five basic operations: the photo-chemical etching of the platelets; the platelet stacking and subassembly brazing; electrical discharge machining of the propellant inlet plenums and machining, grinding and fitting the brazed subassembly to the injector manifold; the manifold platelet stack brazing; and the final machining to finish dimensions. Two leak check operations are performed during the fabrication sequence. The first leak check is made prior to brazing the platelet subassembly to the manifold. This insures that no leakage occurs between the oxidizer and fuel platelets. The second leak check is performed prior to electrical discharge machining the injector face to open the orifices, which is part of the final machining process. The fuel passages are pressurized to insure that no leakage occurs between the fuel and oxidizer circuits; and from the fuel circuit to the outside of the injector.

(U) The material used to fabricate all injector components was 347 Stainless Steel. The platelets were nickel-flashed and the metering platelets were copper plated over the nickel flash to provide the first braze alloy. Oxygen-free high conductivity copper foil was used to braze the end plates to the platelet stack. For the final braze Nioro foil and powder were used.

TABLE IV

HARDWARE FABRICATION SUMMARY

FABRICATION SUMMARY

Number	Nomenclature	Quantity
1156340-1	Segment Chamber	2
1158936-1	Chamber Extension	1
1157383-9	Resonator	1
1156551-1	Chamber Housing Forward	2
1156552-1	Chamber Housing Aft	2
1156553-2	Chamber Housing Main Body	2
1156230-1	Injector (SO/SF)	3
1156230-2	Injector (SO/IF)	4
1157236-1	Injector (IO/IF)	2
1157464-1	Injector (IO/IF)	24
1157464-1M	Injector Dual Manifold (IO/IF)	1

V, Component Fabrication (cont.)

(U) It is significant to note that the fabrication of the 24 IO/IF injectors in the Phase II production run was completed with no difficulties and that all injectors were acceptable units for the clustered segment test program. These units were acceptance test fired at the 20K thrust level. The flow data obtained during this test series are included in Table I.

(C) The durability of the injector was demonstrated during the program when a total of 199 tests were conducted for a total duration of 664.3 sec. There was no structural failure or distortion in any injector. During the segment program one injector was fired 87 times for a total duration of 202.8 seconds; chamber pressure ranged from 700 psia to 4390 psia; mixture ratio ranged from 10.7 to 21.8; and the unit was pulsed with a 15-grain charge at the 9K, 25K, and 44K levels. No mechanical failure was noted during the entire series.

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VI. SEGMENT TEST PROGRAM

A. SUMMARY

(U) The objectives of the segment test program were to: (1) evaluate injector design variations of full scale injector modules at several thrust levels over the 10:1 throttling range, (2) conduct demonstration tests of long duration at full thrust, minimum thrust, and at points in between, and (3) evaluate the dynamic stability characteristics of the selected injector design by shocking the chamber with a pulse gun. For the demonstration tests, the success criteria for acceptable combustion stability characteristics was that the chamber pressure oscillations during steady-state operation should not exceed $\pm$ 5.0% of the average chamber pressure value and not be divergent with time. Also, the effect of measured temperature distribution on engine operation was to be analytically evaluated, with corrections incorporated if found necessary.

(U) The test program was initiated on 27 January 1969 and concluded on 12 December 1969, during which period 176 tests were conducted. The test conditions, objectives and results for the cluster test program are summarized in Table V. The test data summary is shown in Table I. Four different injector designs were evaluated during the program, including the SO/IF, SO/SF, IO/IF, and dual-manifold IO/IF configurations.

(C) The SO/IF and SO/SF injectors were evaluated in parallel during the first portion of the test program. The test data showed that the combustion characteristics with the SO/IF injector were far smoother than with the SO/SF injector, as can be seen on representative oscillograph traces from similar tests, shown in Figure 20. As a result, testing was discontinued with the SO/SF injector, while the SO/IF injector was evaluated in depth, with a total of 87 tests performed with that design. Low frequency "chugging" type oscillations were encountered below the 18K thrust level; efforts to

TABLE V

TEST CONDITIONS AND OBJECTIVES - SEGMENT PROGRAM

Test Series	Run No. SP-30	Test Objective	Test Results
I	101-104	10K Data Point; Test Stand Checkout and MR Survey; SO/IF Injector	No hardware damage; all tests unstable 240 H_Z; MR range 12.9 to 21.8.
II	105-110	18K Data Point; Injector Evaluation and MR Survey; SO/IF Injector	No hardware damage; all tests stable; MR range 13.0 to 16:1; long duration test - 10.28 seconds steady state.
III	111-114	25K Data Point; Injector Evaluation and MR Survey; SO/IF Injector	No hardware damage; all tests stable; MR range 11.7 to 15.4.
IV	115 and 131	18K Data Point and 10K Data Point Injector Evaluation; SO/SF Injector	No hardware damage; unstable - 480 H_Z at 18K point; unstable - 320 H_Z at 10K point.
V	116-118	37.5K Data Point; Injector Evaluation; SO/IF Injector	No hardware damage; all tests stable; long duration test 9.63 seconds steady state.
VI	119-126	44K Data Point; Injector Evaluation; stability evaluation; long duration demonstration; SO/IF injector	No hardware damage; all tests stable; 15 grain pulse charge attenuated; long duration test 9.60 seconds steady state.
VII	127	25K Data Point; Stability Evaluation; SO/IF Injector	No hardware damage; test stable; 15 grain pulse charge attenuated.
VIII	128-141	10K Data Point and 18K Data Point; Test facility coupling characteristics evaluation; SO/IF Injector	No hardware damage; all tests unstable - 320 H_Z to 500 H_Z; varied line resonant frequencies by changing venturis and line orifices; test hardware sympathetic to all frequencies in range noted above.

TABLE V (cont.)

Test Series	Run No. SP-30	Test Objective	Test Results
IX	142-148	10K, 14K, 18K, 25K Data Point; Stability Evaluation with Chamber L* section; SO/IF Injector.	No hardware damage; 10K and 14K points unstable - 250 and 340 H_Z; 18K and 25K points stable.
X	149-151	18K Data Point, Turbulator Evaluation; SO/IF Injector.	No hardware damage; all tests unstable; no significant change in temperature profile due to turbulence devices.
XI	152-157	10K, 12K, 14K, 18K Data Points; Injector Evaluation; IO/IF Injector.	Injector separator plates collapsed in the plenum area; 10K test unstable - 240 H_Z; 12K marginally stable - 260 H_Z; 14K marginally stable - 400 H_Z; 18K test stable; new injector required to resume injector development testing.
XII	158-194	10K Data Point; Stability Evaluation with resonator; SO/IF Injector.	No hardware damage; resonator cavity varied from 0.0 in. to 0.4 in. stroke on 4 hole resonator; 0.4 in. to 0.8 in. stroke on 8 hole resonator, 0.425 to 1.00 in. stroke on 12 hole resonator; no noticeable improvement in stability with this resonator design.
XIII	195-212	5K through 42K data points; Demonstration tests and stability evaluation at 9K, 25K and 42K; IO/IF modified design injector.	No hardware damage; 9K test duration 72.0 seconds, 25K test duration 23.0 seconds, 42K test duration 10.5 seconds; 10K and 12K tests unstable W/O L* section; 14K, 15K tests marginally stable

TABLE V (cont.)

Test Series	Run No. SP-30	Test Objective	Test Results
XIII (cont.)			W/O L* section; all tests 9K and above stable with L* section; 8.5K marginally stable with L* section; 5K and 7.5K unstable with L* at 110 H_Z and 180 H_Z respectively; all three pulse tests attenuated the 15 grain charge within 40 milliseconds.
XIV	213-264	20K Data Point; Injector acceptance test and balance tests for Clustered Segment Test Program.	Minor erosion sustained on injectors and chamber housing while testing S/N 022 and S/N 024 injectors, tested W/O turbine simulator orifice; high frequency (1120 H_Z) oscillations with amplitudies of $\pm$ 150 psi occurred on both tests.
XV	265-276	5K, 6K, 7K, 7.5K Data Points; Injector Evaluation; Dual Manifold Injector.	5K and 7.5K test stable with single circuits flowing; unit unstable when both fuel and/or both oxidizer circuits flowing; no appreciable improvement in stability by dual manifolding only one circuit.

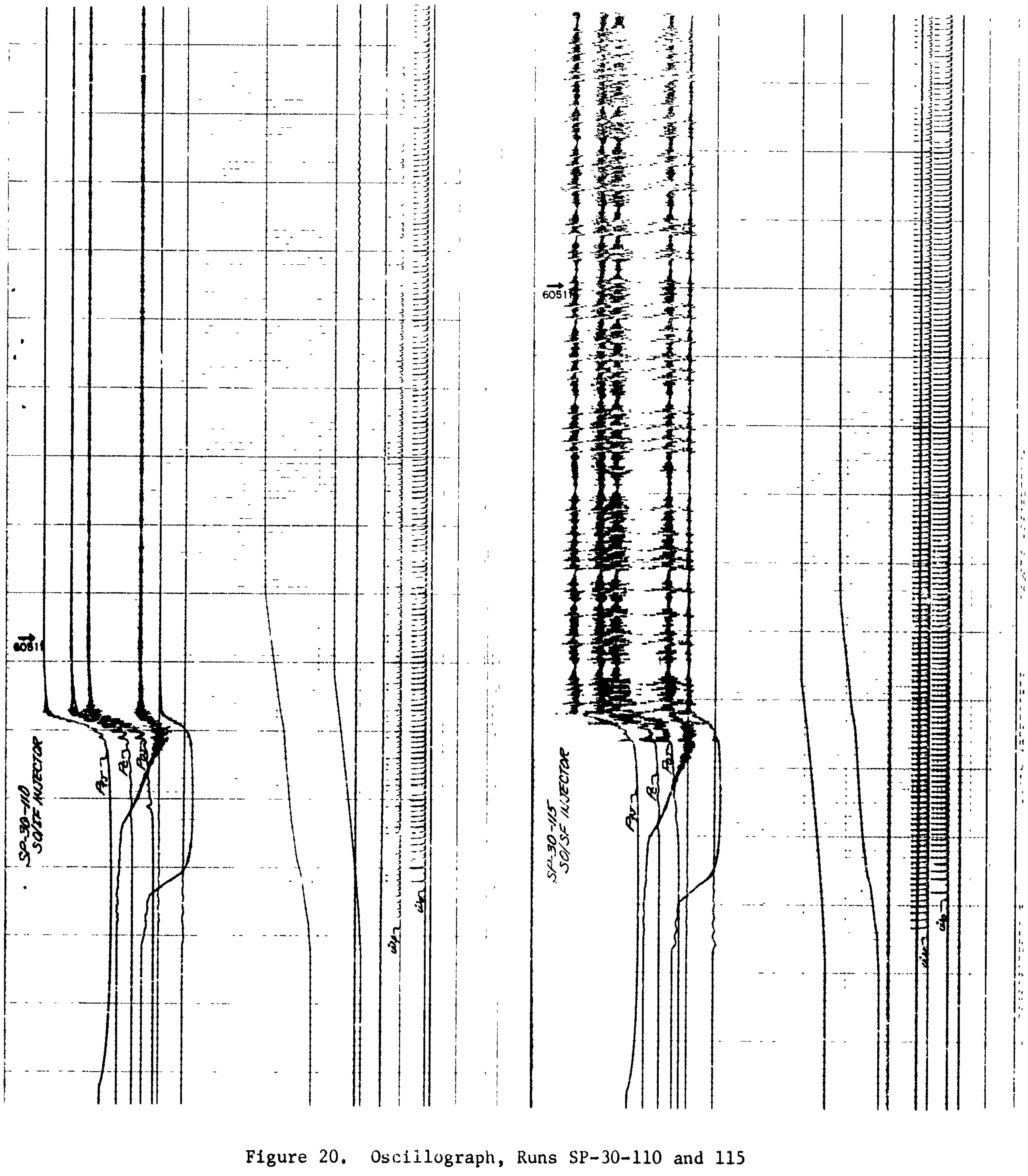

Figure 20. Oscillograph, Runs SP-30-110 and 115

stabilize the operation at the low levels with an acoustic resonator were generally unsuccessful. It was concluded that the injector circuit pressure drops would have to be increased to widen the stable operating range.

(C) The test program was resumed with the IO/IF injector, which incorporated increased circuit stiffnesses as well as other design changes suggested by evaluation of data from tests with previous injectors. The operating characteristics of this injector were clearly superior to the earlier designs. Operation was extremely smooth at all equivalent thrust levels above 8.5K, with chamber pressure oscillations being $\leq \pm 1\%$ of average chamber pressure. Performance and gas temperature distribution were also acceptable. The test unit was pulsed with a 15-grain charge during operation at the 9K, 25K and 42K thrust levels. The unit proved dynamically stable in each test. Following the momentary pressure overshoot resulting from the pulse charge, operation returned to normal within 20 millisec. A typical pulse trace is shown in Figure 21.

(C) In the thrust range between 5 and 8.5K, an organized low frequency "chugging" instability occurred again, due to insufficient pressure drop through the injector orifices. Because of the otherwise excellent results with this injector, authorization was received to proceed into the Phase II clustered segment test program with the IO/IF injector. Subsequently, 24 additional units of that design were fabricated and acceptance test fired for Phase II testing.

(C) Concurrently with the Phase II program, the dual-manifold IO/IF injector was designed to increase the circuit pressure drops at the low throttle points while not increasing the pressure drops at full thrust flows. One injector module of this configuration was fabricated and tested. Stable operation at the 5K level was demonstrated.

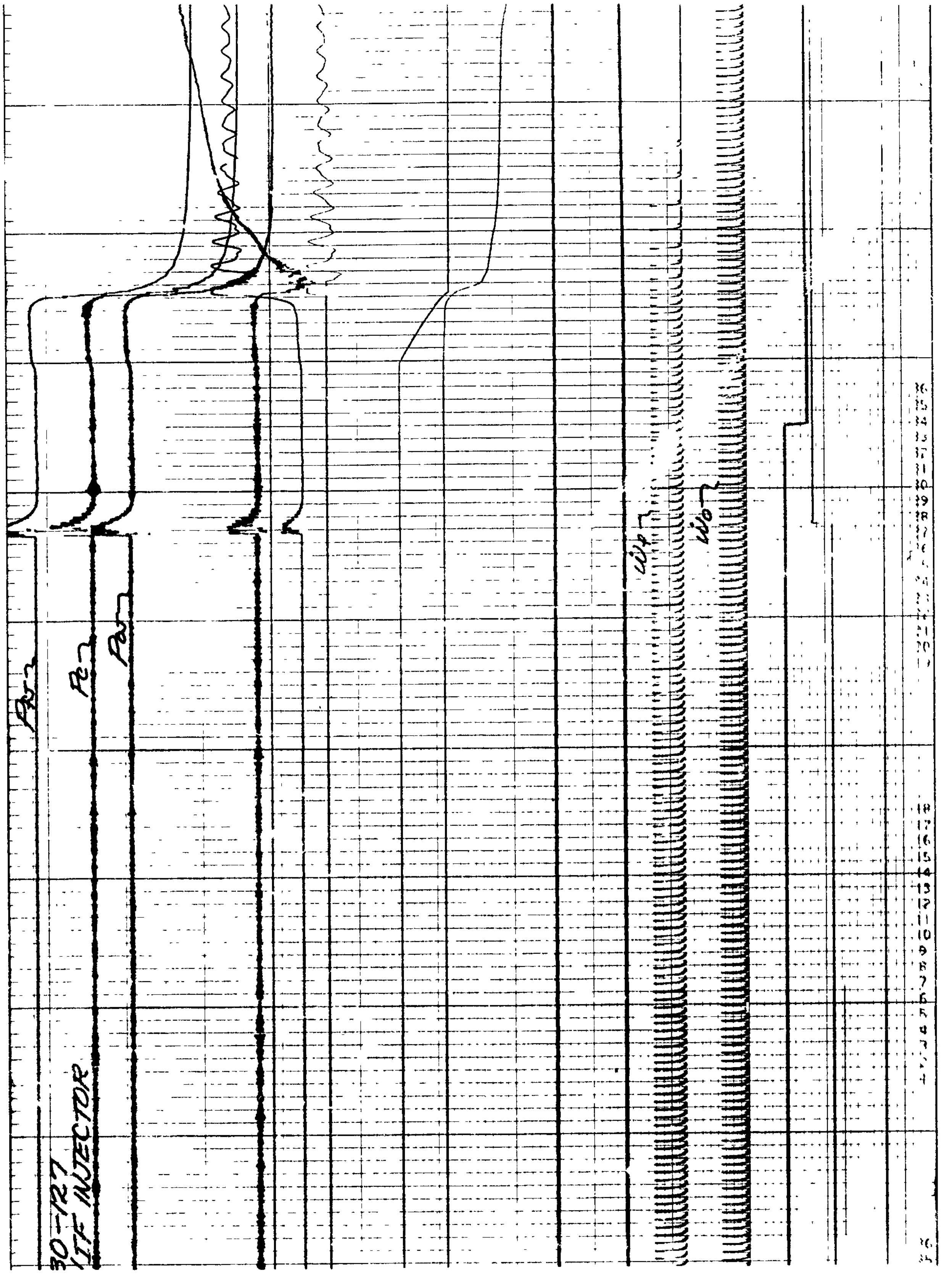

Figure 21. Oscillograph Record SP-30-127

VI, A, Summary (cont.)

(U) A description of the test setup and instrumentation is given in Section VI,B. The detailed test program performed is discussed in Section VI,C. The evaluation of the test data, including performance and stability, is discussed in Section VI,D.

B. TEST SETUP

(C) The segment test program was conducted in Aerojet's Physics Laboratory, Test Bay 6. A photograph of the test installation is shown in Figure 22; the flow schematic is given in Figure 23. Both oxidizer and fuel propellants were supplied to the test unit from high pressure storage tanks pressurized with nitrogen gas. Cavitating venturis installed in the propellant feed lines to the injector were used for flow rate control. (During the low frequency instability evaluation portion of the program, several tests were performed with the venturis removed to determine if changing the feed system configuration would change the basic stability characteristics of the system. It was concluded the venturis were not the controlling factor in the instability).

(U) The test instrumentation consisted of Taber transducers for pressure measurement, Potter turbine-type flowmeters for flow measurement, and 1/8 in. chromel-alumel (C-A) thermocouples for temperature measurement. In addition, high frequency pressure instrumentation included a flush-mounted Photocon 307 transducer in the combustion chamber, and flush-mounted Kistler 601A transducers on the oxidizer and fuel propellant lines just upstream of the injector. The gas temperature profile exiting the chamber was measured by high response, 0.040 in. dia, C-A thermocouples. The chamber also contained a gun port to allow stability evaluation by pulsing the chamber during selected tests with a 15-grain charge.

Figure 22. Physics Lab Test Installation

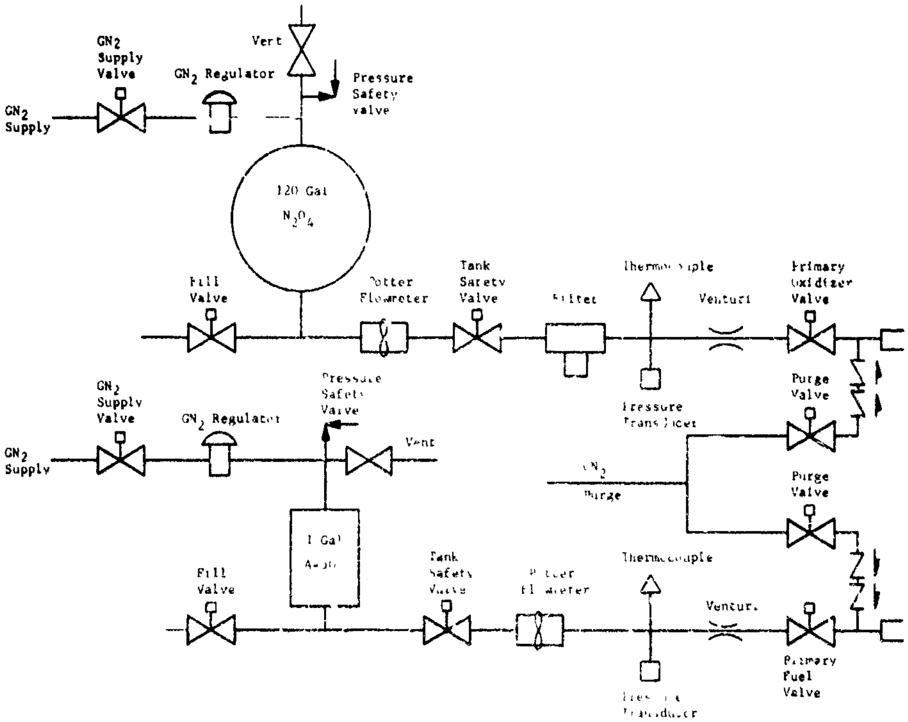

Figure 23. Flow Schematic - Physics Lab Testing

C. DETAILED TEST PROGRAM

(U) The detailed test program performed with each of the four injector designs are discussed in this section. A summary is first given for the evaluation performed with each injector type, followed by a discussion of each test series performed during the evaluation. The test series designation refers to the chronological test sequence of all injectors, and is therefore not necessarily sequential within each specific injector evaluation.

1. SO/IF Injector Evaluation

a. Summary

(C) The segment test program was initiated on 27 January 1969 using the SO/IF injector. In the first test series of 49 tests, injector operation was evaluated at conditions equivalent to a thrust range of 10 - 44K. Operation throughout this range was satisfactory with respect to performance and structural integrity of the injector. However, at thrust levels of 18K and lower, pressure oscillations of $\pm$ 25% of nominal chamber pressure at 260 cps at the 10K level, decreasing to $\pm$ 12% at 450 cps at the 18K level, were encountered. At all thrust levels above 18K, no organized pressure oscillations were present. In fact, operation was very smooth, with chamber pressure oscillations being below $\pm$ 1%. Tests were performed to determine if the oscillations were caused by coupling with the test stand feed system. It was determined that they were not, and that the unstable loop was between the combustion chamber and injector feed manifolds.

(C) Thirty seven additional tests were then performed in which a resonator was attached to the combustion chamber in an attempt to suppress the oscillations. Using the resonator, stable operation was obtained

at the 10K level; however, the resonator was highly selective to the unstable frequency it would damp, and since the combustion frequency changes with each thrust level, it was concluded that the best approach for eliminating the oscillations would be an injector redesigned with high circuit pressure drops to increase the injector stiffness.

b. Test Series I (SP-30-101 through 104)

(C) The primary test objective of this series was to define the injector operating characteristics at the 10K thrust flow rates. Injector mixture ratio was intentionally varied during this series, with data points obtained for mixture ratios from 12.9 to 21.8. The test durations ranged from 0.28 to 0.90 sec of steady state. The unit was unstable at all mixture ratios, with chamber pressure oscillating at 250 psi peak-to-peak at 240 Hz.

c. Test Series II (SP-30-105 through 110)

(C) Test series II was conducted at the 18K level to determine if the increased injector stiffness resulting from the higher flow rates was sufficient to stabilize combustion. Test durations ranged from 1.35 to 10.28 sec of steady state and six mixture ratio data points were obtained between 13.0 and 16.1. All tests in this series were stable tests, with the exception of test SP-30-108, during which chamber pressure began to oscillate at 500 Hz with amplitudes up to 180 psi peak-to-peak. The oscillations occurred first at 2.91 sec into the test, but recovery was effected after 0.470 sec, with stable operation continuing for 4.48 sec. The oscillation reoccurred at that point and was sustained for the remaining 1.50 seconds of the run. Based on these tests, it was concluded that stable operation at the 18K thrust level was marginal. The measured oxidizer and fuel pressure drops were 126 and 202 psi, respectively.

VI, C, Detailed Test Program (cont.)

d. Test Series III (SP-30-111 through 114)

(C) This series of four tests was conducted at the 25K operating point at approximately 2100 psi chamber pressure. Mixture ratio was varied from 11.7 to 15.4. The tests were stable and satisfactory in all respects.

e. Test Series V (SP-30-116 through 118)

(C) The objective of this series was to obtain data at the 37K operating point. Three tests were conducted from 2.18 to 9.63 sec duration at chamber pressures between 3221 and 3251 psia. The tests were stable and satisfactory in all respects.

f. Test Series VI (SP-30-119 through 126)

(C) This series was designed to evaluate the operating characteristics in the 40 to 50K range. The upper thrust limit to which the injector could be tested was 45K, due to the pressure supply capability of the test facility. During this series, three satisfactory long-duration runs (9.2, 9.6 and 9.6 sec) were conducted, which demonstrated the stability and structural adequacy of the design. Also during this series, the unit was pulsed with a 15-grain charge at a steady state chamber pressure of 4376 psia. The pulse charge produced an 820 psi spike in chamber pressure; the perturbation was completely attenuated in 0.020 sec.

g. Test Series VII (SP-30-127)

(C) This test was a pulse test at the 25K point to evaluate the stability characteristics at an intermediate throttle point. The test was 19.2 seconds in duration with the 15-grain pulse initiated at a steady state

chamber pressure of 2285 psi, just prior to shutdown. A 650 psi spike was noted following the pulse, which was attenuated in 0.020 sec.

h. Test Series VIII (SP-30-128 through 142)

(C) Having demonstrated the adequacy of the design over the high range throttling, this series was designed to evaluate, and eliminate if possible, the oscillations noted at the throttle points below 18K. During this series 14 tests were conducted, two at 10K and twelve at 18K. All tests conducted during this series were unstable. Variations of test setup, designed to evaluate the influence of the test facility components on the instability, included moving the venturis to a new location to change system resonances, and replacing the venturis with orifices. No effect was noted on the combustion characteristics other than slight changes in frequency. Attention was turned to the injector and an additional 100 psi orifice was placed in the oxidizer inlet to attempt to isolate the oxidizer circuit. An increase in nozzle area to increase the injector pressure drop while maintaining chamber pressure was also investigated. Neither modification had any marked effect on combustion. The oxidizer inlet to the chamber, in the region where it transitions from round to rectangular shape, was modified to streamline the transition geometry; it was tnought that the original configuration, which contained a sharp discontinuity, could induce cyclic flow separation from the wall (flutter) and thus act as a fluid oscillator. No improvement was noted.

i. Test Series IX (SP-30-143 through 148)

(C) Test series IX was an evaluation of an L* extension added to the combustion chamber. This extension was designed to more nearly simulate the chamber conditions of the engine, which has a subsonic turbine at the location of the sonic nozzle of the test chamber. The sonic nozzle was replaced by an orifice, and an extension added, sized to provide the equivalent volume (for one segment) from the turbine to the secondary

injector face. This change provided consistent stable operation at the 18K thrust level, but the unit remained unstable at lower thrust levels. Following an evaluation at 25K, the L* extension was removed and the test repeated to verify stable operation of the basic configuration at the 25K level. Operation was stable. It was concluded that, while the L* extension did provide stable operation at 18K, the chance of obtaining stable operation down to the 5K level by combustion volume changes was remote.

j. Test Series X (SP-30-149 through 151)

(C) This series was performed to determine if turbulators installed in the combustion chamber would improve the stability range of the system, since the analysis indicated that forced mixing would tend to increase the heat transfer rate and gas temperatures. The tests were performed at the 18K thrust level, previously established as the marginal operating range. Three turbulator concepts were evaluated, including (1) a series of three splash plates, (2) a multi-hole orifice plate, and (3) a double row of triangular bars. Figure 24 is a photograph showing the posttest condition of the turbulators. No damage, except minor sagging, was noted on any of the turbulators. Their presence in the chamber reduced the chamber volume and changed the effective chamber dimensions which establish the chamber acoustics; as a result the combustion frequencies varied significantly (1100, 460 and 970 cps for the three designs, respectively). However, operation remained unstable in all cases, and no further testing with the turbulators was performed.

k. Test Series XII (SP-30-158 through 194)

(C) This test series was performed to determine if an Helmholtz resonator attached to the combustion chamber would damp the unstable oscillations and improve the stable throttling range of the injector. The resonator was designed with an adjustable volume feature;

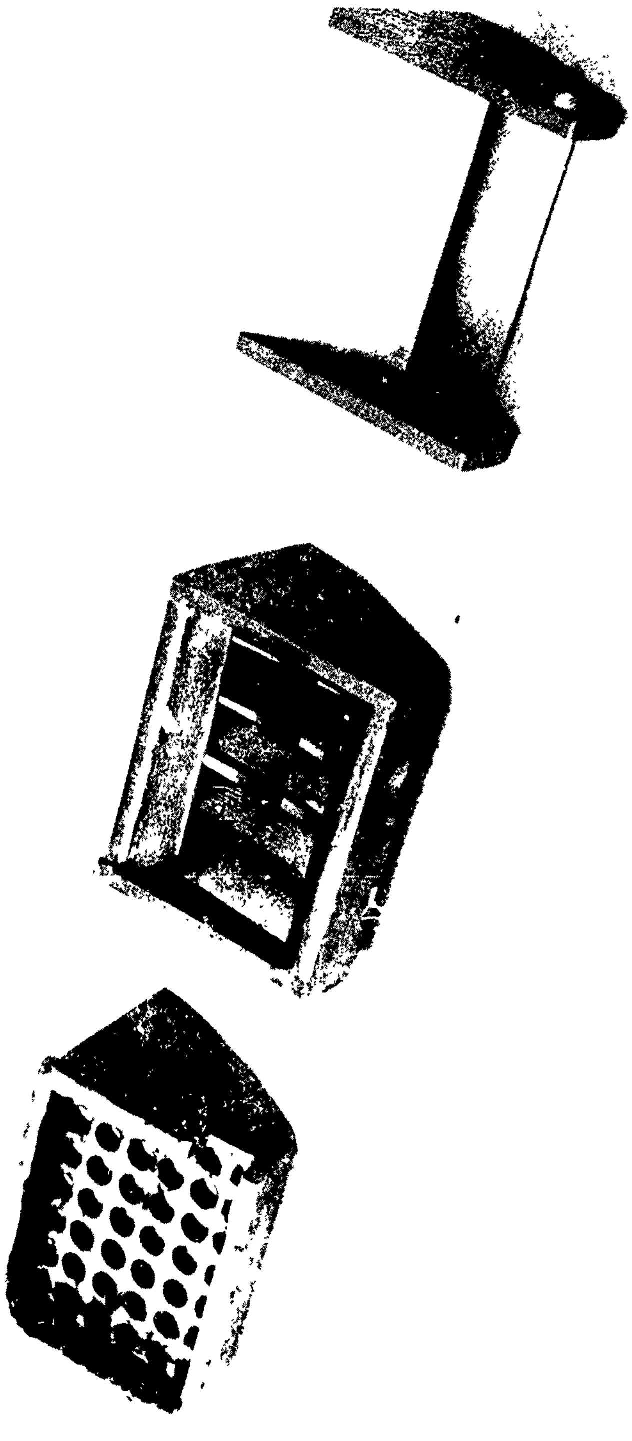

Figure 24. Turbulator

the basic testing approach was to vary the volume setting in an attempt to obtain stable operation. All tests--with the exception of one--were conducted at the 10K level, a throttle point which had always produced unstable operation. Stable operation was achieved during three tests. However, later in the test series, operation was unstable at the same resonator volume settings. The resonator design and test results are discussed in Section VI,D,3. The test data obtained with the test resonator showed that it was not probable that a resonator of reasonable size would be effective in damping the unstable oscillations.

(C) Up to this point in the test program, three different approaches had been pursued with the SO/IF injector in attempts to eliminate the low frequency oscillations at the lower throttle levels: (1) test system changes; (2) turbulators, and (3) the resonator. None of these attempts significantly changed the throttling range capability of the injector. It was concluded that the injector circuit pressure drops would have to be increased to effect a significant improvement in the throttling range. On this basis, no additional testing was performed with the SO/IF injector; direction was focused on the IO/IF injector, which had been designed with increased circuit pressure drops.

2. SO/SF Injector Evaluation
Test Series IV (SP-30-115 and -131)

(C) Two tests were performed with the SO/SF injector, one at the 10K thrust level and one at 18K. In both tests operation was very rough, with frequent intermittent "popping" in the combustion chamber which caused pressure spikes of up to 60% P_c overpressure. The oscillograph trace of the 18K test is shown in Figure 20. Based on the clearly superior operation of the SO/IF injector, no further testing was performed with the SO/SF injector.

VI, C, Detailed Test Program (cont.)

3. IO/IF Injector Evaluation

a. Summary

(C) The IO/IF injector, which was designed with higher circuit pressure drops on the basis of test results with the SO/IF and SO/SF patterns, was evaluated in two development test series totaling 24 tests. Operation was evaluated over a thrust range from 5-42K and included tests both with and without the chamber L* extension installed. Without the extension, operation was marginally stable in the 12-14K range. With the chamber extension installed, operation was stable at 9K and above, and operation was satisfactory in every respect. Low frequency pressure oscillations were encountered in the 5 to 8.5K thrust range, ranging from ± 15% and 110 Hz at 5K to ± 4% and 200 Hz at 8.5K. Except for these relatively low amplitude oscillations, combustion was smooth and operation was satisfactory.

(C) Based on the fact that stable operation was demonstrated for over 90% of the intended throttling range, Phase I development testing was concluded with the IO/IF injector selected for Phase II testing. Subsequently, 24 of these injectors were fabricated and acceptance test fired in Test Series XIV for use in the Phase II cluster program.

b. Test Series XI (SP-30-152 through -157)

(C) The IO/IF injector was tested over the range of 10-18K thrust in this series of six tests. Operation was stable at 18K, unstable at 10K, and marginally stable in the 12-14K range. These tests were all conducted without the chamber extension installed. Inspection of the test records showed a "pop" in the propellant circuits just before ignition, indicative of an inter-propellant leak. Subsequent water testing with the

injector confirmed the leak, and determined its location as being in the vicinity of the fuel manifold. The leak must have d eloped during testing or just prior to testing during a routine acid flush operation, since the injector had previously passed an interchannel leak test.

(C) Operation with this injector was substantially improved over the original injector design, which was marginally stable at 18K. Because of the interpropellant leak, which was determined to be non-repairable, the test series was concluded until a new injector could be fabricated.

c. Test Series XIII (SP-30-195-212)

(C) Test evaluation of the IO/IF injector was resumed with a new unit during this 18-test series. Tests were performed over the equivalent thrust range of 5-42K. The initial tests were made without the chamber extension. In this configuration, operation was marginally stable in the 14-15K thrust range, and unstable at 10K. With the extension added, operation at 9K and above was stable and satisfactory in every respect. Low frequency pressure oscillations were encountered between 5 and 8.5K, ranging from $\pm$ 15% P_c and 110 Hz at 5K to $\pm$ 4% and 200 Hz at 8.5K.

(C) Demonstration tests included a 72-sec test at 9K, and a 23-sec test at 25K, and a 10-sec test at 42K. Each of these tests included a pulse from a 15-grain charge during the steady-state portion of the run; attenuation was complete in all cases within 0.040 sec

d. Test Series XIV (SP-30-213 through 264)

(C) This series was performed to qualify injectors for the clustered segment test program. Twenty four injectors were test-fired

during the series, all at the 20K thrust level. The series was designed to identify the base point circuit pressure drops and to balance, by means of propellant inlet orifices, a group of 10 injectors for clustered testing. Performance, structural integrity, and erosion-free operation were also demonstrated during the series.

4. Dual-Manifold IO/IF Injector Evaluation; Test Series XV (SP-30-265 through 276)

(C) This test series was designed to evaluate the dual manifold injector, the last of the 25 injectors committed to the test program. Eleven tests were conducted to define the operating characteristics using the following manifold combinations: first, one fuel circuit and one oxidizer circuit; second, both fuel circuits and one oxidizer circuit; third, both fuel circuits and both oxidizer circuits and; fourth, one fuel circuit and both oxidizer circuits.

(C) Five tests were conducted at the 5K thrust point with durations ranging from 1.50 to 10.0 sec of steady state operation, and chamber pressure ranging from 258 to 280 psia. Only one fuel and one oxidizer circuits were opened for this group of tests, and stable combustion was noted on all tests. Two tests were conducted at the 7.5K point with stable combustion resulting.

(C) The second fuel circuit was then opened and a test was conducted at the 5K point with a single oxidizer circuit and double fuel circuits. The result was unstable combustion at 87 Hz and 106 psi peak-to-peak oscillations at a chamber pressure of 280 psia.

VI, C, Detailed Test Program (cont.)

(C) The second oxidizer circuit was machined open and a test performed using both oxidizer and both fuel circuits. (This configuration is identical to the IO/IF injector design except that the fuel circuit is fed from two separate inlets). This configuration was also unstable. Oscillations of 124 psi and 63 Hz were noted.

(C) The third configuration (both oxidizer circuits and single fuel circuit) was evaluated through a thrust range of 5K, 6K and 7K. This configuration lends itself most readily to the MIST engine design, since only minor modification to the engine design would be required to dual manifold the fuel circuit. Chamber pressures for the tests were 284, 373 and 411 psia, respectively. Unstable combustion resulted at all three points with frequencies of 54, 95 and 115 Hz recorded; and amplitudes of 122, 103, and 77 psi noted in chamber pressure.

(C) It was concluded from this testing that to achieve the full 10:1 throttling range, the primary injector would have to incorporate dual manifolds in both the fuel and oxidizer circuits. At the lower thrust levels, only one circuit for each propellant would be opened, duplicating the conditions for the first tests in this series. The impact of this configuration on the overall engine design is discussed in the appendix.

D. TEST DATA ANALYSIS

1. Performance

(C) Performance of the segment primary combustor was evaluated with respect to characteristic exhaust velocity and hot gas temperature variation. Characteristic exhaust velocity performance was analyzed on all stable tests conducted during the primary combustor segment test program. This evaluation encompassed a total of 97 tests on three injectors over a chamber pressure operating range of 258 to 4390 psia and a mixture ratio range of 10.7 to 27. Achieved performance characteristically followed partial equilibrium theoretical performance with the actual combustion efficiencies following predicted trends with chamber pressure and mixture ratio as previously discussed in Section IV,A. A complete summary of the performance test data appears in Table I. The following discussions define the method of analysis used in these evaluations as well as detailed discussions of the performance of each of the HIPERTHIN injector concepts tested as functions of mixture ratio and chamber pressure. Temperature discussion follows this discussion.

(U) HIPERTHIN injector performance was evaluated in terms of characteristic exhaust velocity since the tests were conducted without thrust measurements thereby precluding use of the ICRPG approved method[(1)] using energy release efficiency.

(U) The basic procedure involved calculating characteristic exhaust velocity by:

$$c^* = P_c \, A_t \, g/\dot{w}_t$$

(1) J. L. Pieper, ICRPG Liquid Propellant Thrust Chamber Performance Evaluation Manual, Chemical Propulsion Information Agency, Report 178, September 1968.

VI, D, Test Data Analysis (cont.)

where:

P_c = Chamber pressure as measured on PCPC-1 and equated to stagnation conditions using isentropic subsonic compressible flow equations, in psia.

A_t = Throat area as measured in square inches and corrected for nozzle flow coefficients (C_D), which is discussed in later paragraphs.

g = Acceleration of gravity in ft/sec^2 (32.174 ft/sec^2).

$\dot{w}_t$ = Total combustor flow rate as measured in lb per second of propellant by a rotor flow meter located in the propellant feed system.

(U) Theoretical performance was derived using partial equilibrium theory previously presented in the Integrated Components Program Final Report, AFRPL-TR-65-150 Volume III, Section V, "Thermochemical Analysis." This technique assumes that endothermic heating of the nitric oxide (2NO) occurs in sufficiently short periods of time (stay time) to prohibit exothermic decomposition into $N_2 + O_2$ which delivers equilibrium temperatures and characteristic exhaust velocity.

(U) Nozzle throat flow coefficients (C_d) were calculated using two dimensional compressible flow theory taking into account entrance diameter ratio, entrance angle, land width at the throat, and the radius of curvature at the sonic throat. For the nominal four-hole nozzle geometry of the segment tester, a flow coefficient of 0.75 was derived (C_d = 0.75) which thermodynamically reduces the measured throat area to 75% of its geometric value. On some tests the throat area was increased, which has the effect of reducing the flow coefficient due to reduced entrance to throat radius ratio and increased throat land width. These corrections were made to the nominal value for all tests in this category.

VI, D, Test Data Analysis (cont.)

(U) The performance data was classified into three groups pertaining to the three injector designs tested. A total of 97 test data points make up this data package as summarized in Table VI.

a. SO/IF Injector

(C) This injector was the initial injector to be tested in the program and the design incorporated 8600 showerhead oxidizer elements and 315 fuel 90° included angle doublet elements. Element pattern arrays were uniform with the exception of the outermost four rows which had no fuel orifices, producing a small oxidizer film barrier for chamber wall cooling. A total of 28 stable performance tests make up the data package on this injector. These tests were conducted at 10 to 44K equivalent thrust, at chamber pressures of 701 to 4390 psia, and at mixture ratios of 10.7 to 21.8.

(C) The resulting characteristic exhaustic velocity performance correlates well with mixture ratio, as can be seen in Figure 25. The resulting performance efficiencies range from 93% at a mixture ratio of 10.5 to 81% at a mixture ratio of 22. This trend, in percentage of optimum performance, can also be equated to chamber pressure since all low mixture ratio tests were performed at high chamber pressures, while the high mixture ratio tests were conducted at low chamber pressures. These combinations were required to meet engine operating balance points for the staged combustion MIST engine.

(C) Defining this performance in terms of percentage and equating it to operating chamber pressure (thrust level) results in the curve of Figure 26. The predicted line previously defined during design analysis is described in Section IV,A. Interpreting the results clearly defines the endothermic heating process of the oxidizer and how this process is affected

TABLE VI

PERFORMANCE DATA SUMMARY TEST POINTS (U)

PERFORMANCE DATA RANGE

Injector	No. of Performance Data Tests	Thrust Range lbsf	MR Range O/F	P_c Range psia
Showerhead Oxidizer/ Impinging Fuel	28	10 to 44K	10.7 to 21.8	701 - 4390
Impinging Oxidizer/ Impinging Fuel	63	8.5 to	13.1 to 22.2	599 - 3818
Dual Manifold Impinging Oxidizer/ Impinging Fuel	6	5 to 7.5	22.2 to 27	258 - 390

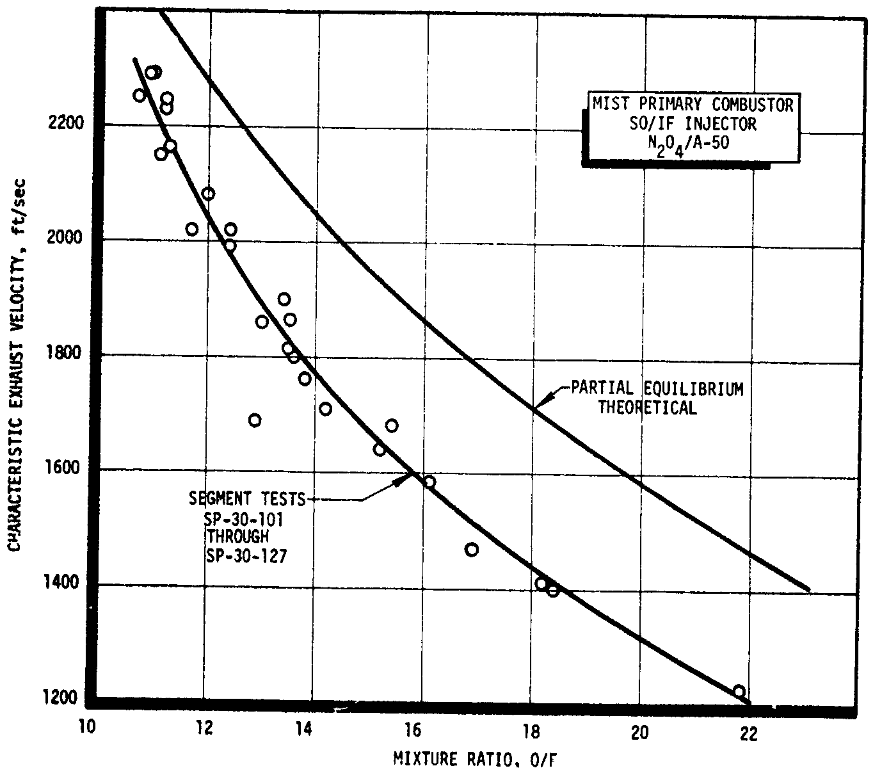

Figure 25. c* vs MR (SO/IF) (U)

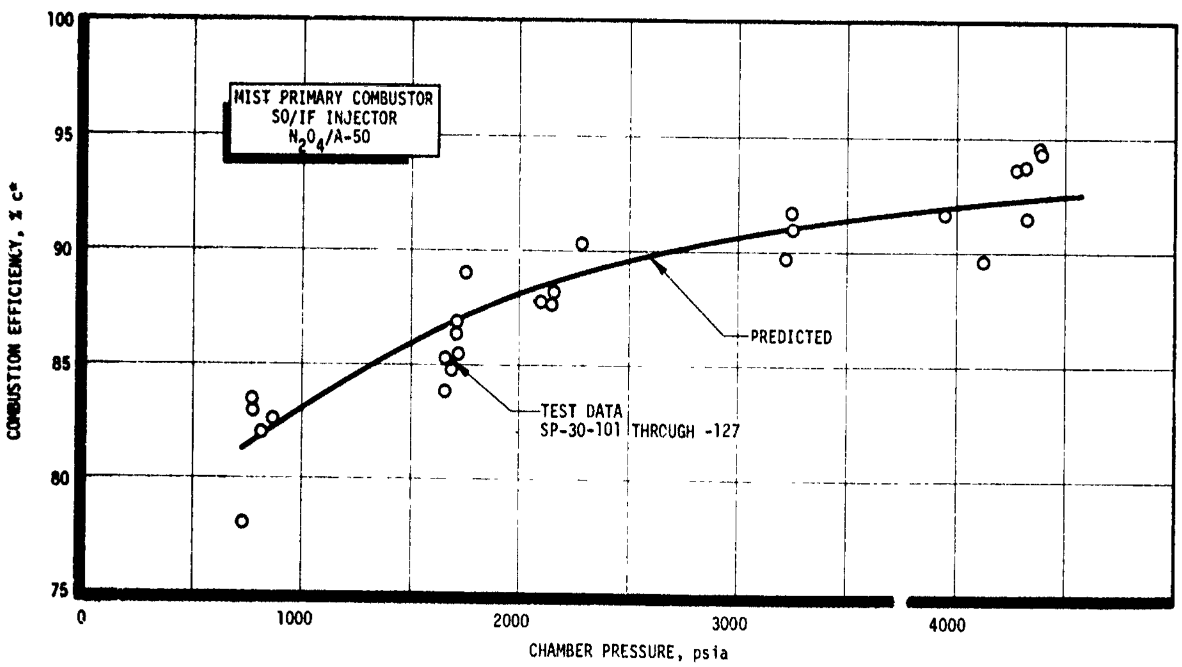

Figure 26. Combustion Efficiency vs P_c (U)

by increased chamber pressure and quantity of fuel corresponding to lower mixture ratios. A lower mixture ratio balance allows more fuel and oxidizer to be reacted stoichiometrically (MR_s = 2.1) enabling a greater quantity of heat to be transferred to the remaining oxidizer. Increases in P_c are also beneficial since they increase the heat transfer rates between the stoichiometric gases and the excess oxidizer, thereby increasing combustor efficiency still further.

(C) It can therefore be concluded the showerhead oxidizer injector with impinging fuel doublets performed as predicted with excellent performance agreement for the conditions at which it was operated.

b. IO/IF Injector

(C) This injector was introduced into the segment test program in an effort to improve stability at low thrust. The injector differed from the showerhead oxidizer design in two ways: the oxidizer circuit had a higher pressure drop, and the 8600 showerhead elements were replaced with 2408 oxidizer 90° impinging doublets.

(C) A total of 63 performance data tests were conducted on this HIPERTHIN injector at thrust levels of 8.5 to 42K. The corresponding mixture ratio range was 13.1 to 22.2. Detailed performance data tabulations appear in Table I.

(C) The resulting characteristic exhaust velocity performance is in direct agreement with the showerhead oxidizer injector performance as analytically predicted. A comparison of the two injectors performance is shown in Figure 27. The data trends indicate slightly higher performance at high mixture ratios resulting from the increased atomization of the higher

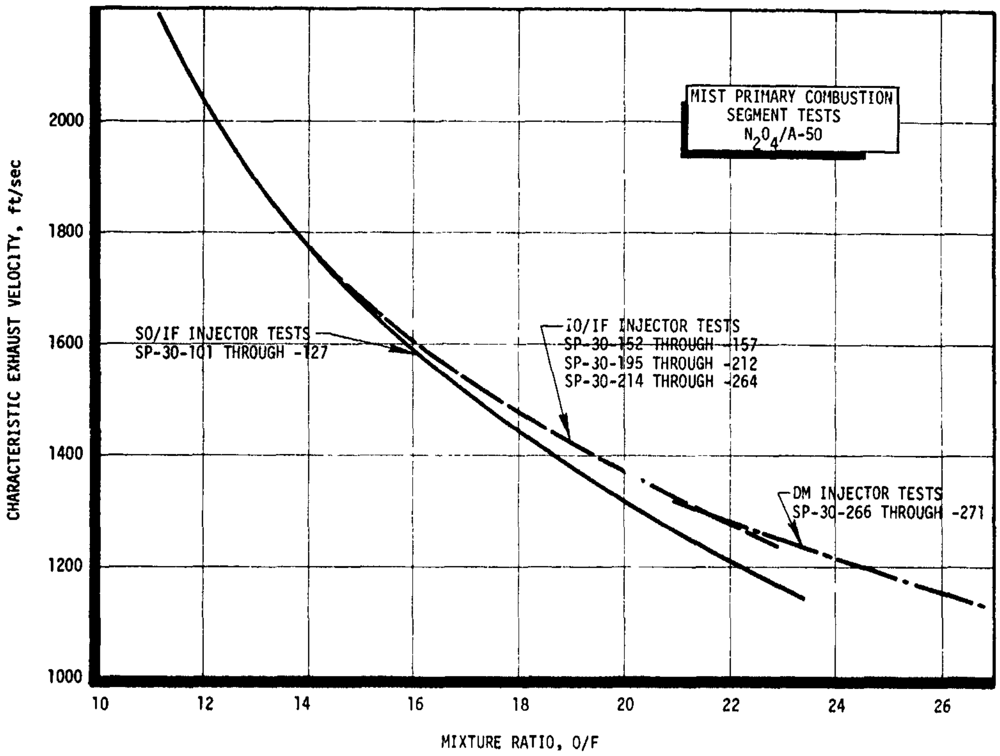

Figure 27. c* vs MR (IO/IF vs SO/IF vs DM) (U)

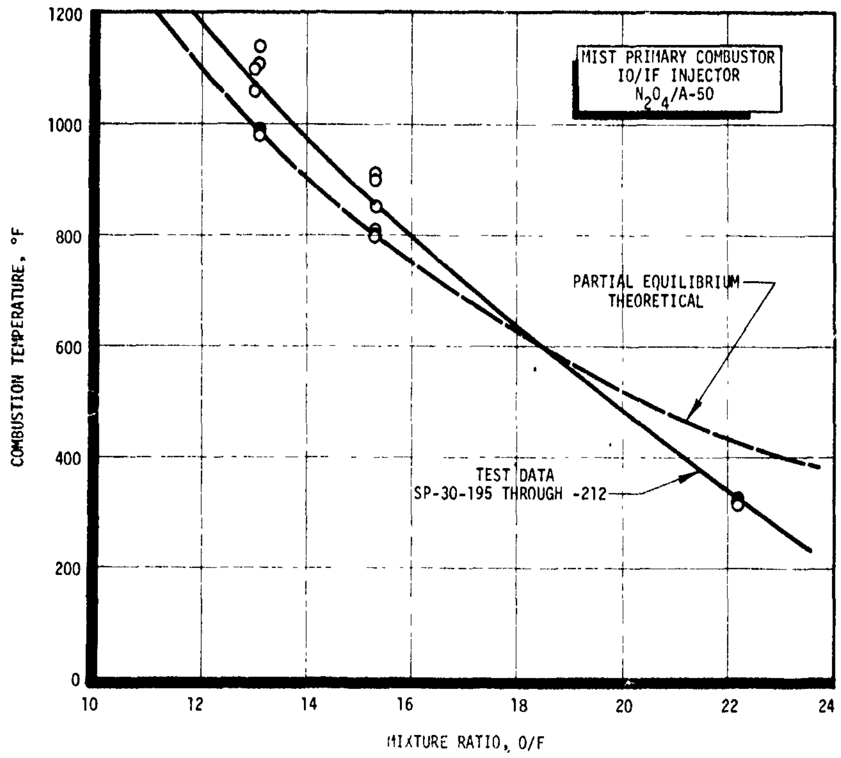

Figure 28. Combustion Temperature vs MR, Segment Tests

ΔP doublet elements. At low mixture ratio (below 16) the variation between the two injectors is well within the data scatter. It is therefore concluded that the impinging oxidizer injector is a superior performing unit since it delivers approximately 5% higher performance at high mixture ratios of 22, and equal performance below a mixture ratio of 16. Again it must be emphasized the high mixture tests were performed at low chamber pressures where it is increasingly difficult to obtain high performance due to the endothermic oxidizer heating process.

c. Dual Manifold Injector

(C) A third injector was evaluated during the program in an effort to improve the low-thrust stability of the combustor. This injector utilized two parallel oxidizer and fuel circuits to allow increased injection pressure drop at low thrusts. Six data point tests were conducted on this injector defining comparable high mixture ratio performance with the impinging oxidizer injector design. This injector was tested from 5K to 7.5K thrust at mixture ratios of from 22 to 27.

(C) Performance comparisons with the showerhead oxidizer, impinging oxidizer and dual manifold injectors are shown in Figure 27. As noted in the illustration, this injector performs as well as, or better than, the impinging design over its tested MR range. This characteristic results due to the increased atomization capability of the higher velocity doublet elements producing more doublet momentum exchange. For this reason the dual manifold design delivers improved performance. Since the observed data trends are in excellent agreement with theoretical predictions it is concluded that high pressure/low MR performance of this injector would be identical to that of the impinging-oxidizer injector. Therefore, the general curve of performance for the impinging-oxidizer injector is considered indicative of performance for the dual manifold design.

d. Temperature Distribution

(U) Temperature data as measured on the three thermocouples located just upstream of the sonic back pressure throat are also presented in the data summary, Table I. The actual temperature distribution for the accepted injector, the impinging oxidizer/impinging fuel, is presented as a function of mixture ratio in Figure 28. These data are in close agreement with theoretical over the entire test range. As previously presented, the theoretical data is generated using the partial equilibrium dissociation model which assumes endothermic heating of the oxidizer. The figure indicates recorded temperature data slightly higher than theoretical at mixture ratios below 18 and slightly lower above this value. In all cases the data is within 100°F of the theoretical values, showing excellent temperature distribution.

2. Primary Combustor Stability Characteristics

(C) Early in the test program, the data showed low frequency coupling between the combustion chamber and the propellant injection circuits. This condition was experienced with both the SO/IF and SO/SF injectors. The test records showed that the oscillations were initiated in the combustion chamber, and coupled first with oxidizer circuit; the fuel circuit coupling was generally noted several hundred milliseconds after the oxidizer had already coupled. The frequency of the coupling was 240 to 250 Hz at the 10K level, with amplitudes up to ± 50% of average chamber pressure.

(C) A study was conducted to determine the possible causes of the oscillatory behavior seen in the propellant feedlines and the combustion chamber. Pressure data was recorded at the venturi inlets, injector inlets (3-in. upstream in the propellant lines), the injector manifolds, and the combustion chamber. Low response Taber transducers were located everywhere except at the

injector inlets and the combustion chamber. High response Kistler Model 601A transducers were used on both the fuel and oxidizer circuit; a Photocon 307 was flush-mounted in the chamber.

(C) The observed frequencies were compared with the theoretical combustion frequencies to determine if a direct correlation existed. The calculated combustion chamber frequencies were determined from the following formula:

$$\text{Frequency} = \frac{\text{acoustic velocity}}{2 \times \text{characteristic length}}$$

where the characteristic lengths represented the chamber's transverse dimensions (1.7 and 2.0 in.) and an injector to nozzle mean length of 3.0 in. The acoustic velocities were calculated from chemical equilibrium properties and are listed in Table VII as functions of the mixture ratio. A propellant line analysis was also made to determine the general range of frequencies possible in the fuel and oxidizer circuits. The termination (boundary) points of the lines were assumed to be the cavitating venturis and the injector inlet. Using both closed end and open end "organ pipe" theory, the fundamental frequencies of oscillation were calculated to be 1300 and 2600 Hz in the fuel circuit and 625 and 1250 Hz in the oxidizer circuit. The fact that the high response Kistler pressure transducers were flush mounted eliminated the possibility of transducer resonances excited by random flow perturbations.

(C) The pressure oscillations observed during the test program all have frequencies below the fundamental values calculated to exist in the feed line between the venturi and injector inlet, as well as the computed fundamental combustion frequencies. The oscillations recorded are therefore functions of a lumped nature associated with the feed system inertance (line length, cross-sectional area, propellant mass flow), an injector resistance characterized by $\frac{\Delta P}{P_c}$, capacitive and resistive combustion chamber affects (c*, L*, etc.) and a suitable characteristic time lag or phase relationship.

TABLE VII

FUNDAMENTAL MODE FREQUENCY FOR VARIOUS MR's

Characteristic Chamber Length (in.)	M.R.	Acoustic Velocity (ft/sec)	Frequency (Hz)
1.7	13.3	1600	5600
	21.8	1178	4160
2.0	13.3	1600	4800
	21.8	1178	3540
3.0	13.3	1600	3200
	21.8	1178	2400

(C) The injector circuit pressure drops were increased with the injector redesign to the IO/IF configuration to improve the system stable operating range. With this new injector, the system did not oscillate at the 18K level. Operation became marginal, however, at the 14 - 15K level, with organized frequency patterns intermittantly appearing during a test. With the chamber extension added to the system, no organized oscillations occurred down to the 8.5K point. The amplitudes of the chamber pressure oscillations at that point were $\pm$ 4% P_c, increasing to $\pm$ 15% P_c at the 5K point. With the subsequent dual-manifold injector, which further increased the injector circuit pressure drop at the low throttle levels, stable operation was demonstrated at the 5K thrust level.

(U) It should be noted that the sonic nozzle used during the test program does not simulate the resistance characteristics of the subsonic turbine assembly used in the full scale engine. The turbine will have a greater damping effect on chamber oscillations, possibly eliminating them altogether; further, the turbine will alter the engine's low frequency response since it forms an integral part of the system.

(C) At all thrust levels above those where the low frequency oscillations occurred, the primary combustor proved to be extremely stable. Chamber pressure was extremely smooth, averaging $\leq \pm$ 1% of average chamber pressure. The assembly was pulsed at the 9K, 25K, and 42K thrust levels with a 15-grain charge; in each instance the momentary disturbance and overpressure was completely attenuated in 0.040 sec or less.

3. Acoustic Resonator Evaluation

(C) An acoustic resonator attached to the preburner chamber was evaluated as a device for suppressing the low frequency oscillations experienced with the SO/IF injector at low throttle ratios. This resonator was an adaptation

of the simple Helmholtz resonator, which is analogous to a spring-mass mechanical damping device. In principle the resonator consists of a rigid enclosed volume, connected to the external medium, i.e., the combustion gases in the chamber, through a small opening of a specific diameter and length. The gases in the opening are considered to move as a unit, and as such are analogous to a mass element of a mechanical oscillator. The alternate compression and expansion of the gas in the enclosed volume is the stiffness element. Finally, the radiation of sound at the opening, which leads to dissipation of acoustic energy, is analogous to the resistance element. This resonator can be "tuned" to damp a specific oscillatory frequency by simply varying its geometric parameters, providing the properties of the gases in the resonator are fixed. The controlling equation is:

$$f_o = \frac{c}{2\pi} \sqrt{\frac{A_o}{\ell_{eff} V}}$$

where:

ℓ_{eff} = $\ell + 0.85\ d_o\ (1 - 0.7\sqrt{\sigma})$

A_o = Area of opening, $\pi\ d_o^2/4$, in.^{2}

c = Speed of sound of gases in resonator, in./sec

d_o = Diameter of opening, in.

f_o = Resonant frequency of resonator, Hz

ℓ = Length of opening of resonator, in.

ℓ_{eff} = Effective length of opening accounting for end effects, in.

V = Volume of resonator cavity, in.^{3}, $A \cdot L$ or $\pi D^2/4 \cdot L$

σ = Fracture of resonator frontal area occupied by A_o/A

A = Area of resonator normal to opening, in.^{2}

L = Length of resonator, in.

D = Diameter of resonator, if of circular cross section, in.

(U) The relationship between the length and diameter of the opening, the volume of the cavity, and the resonant frequency of the resonator can thus be seen. For example, as the cavity volume decreases, the diameter must decrease or the length of the opening must increase to maintain a constant resonant frequency.

VI, D, Test Data Analysis (cont.)

(U) The one geometric parameter that is not included in this relationship is the number of resonator elements which are required to successfully damp a given oscillation. Some experience with larger engines has lead to the preliminary conclusions that the total open area of the Helmholtz resonator must exceed 7% of the active injector area. The application of this criteria to a primary combustor of this nature was of uncertain validity and was therefore used only as a starting point. The resonator designed for this program included a ratio of resonator to injector area range of 2 to 25% by virtue of a design feature which allowed the cavity volume to be adjusted as the number of resonator openings was changed from test to test.

(C) The unstable frequencies experienced in the injector test program varied from approximately 200 - 500 Hz over the thrust range from 10-18K, with corresponding combustion temperatures of 280° to 1000°R. The higher temperatures occurred at the higher thrust levels because the injector was operated at lower mixture ratios. The combustion frequency, which also increased with increasing thrust level, was the result of changed acoustics at the different thrust levels. The resonator design was based upon analyses to determine the required relationship between the passage length, diameter, and resonant volume, as well as practical constraints imposed by the engine design. Obviously, if a resonator was to be used in the engine, it must be compatible with the engine design and of a reasonable size. It was determined that up to eight holes of 1/4 in. dia could be drilled into the upper portion of secondary injector flange joining each primary combustor segment, with a resonator cavity located circumferentially around the engine just below the turbopump housing. The passage length required for such an installation is 3.0 in. This formed the basis for the resonator design, shown in Figure 29. It consists of twelve 3-in.-long, 1/4 in. holes leading to a resonant cavity 3-in. in diameter, the length of which is adjustable by means of a screw-adjusted piston. The resonator is designed to attach to the chamber in the existing pulse gun port.

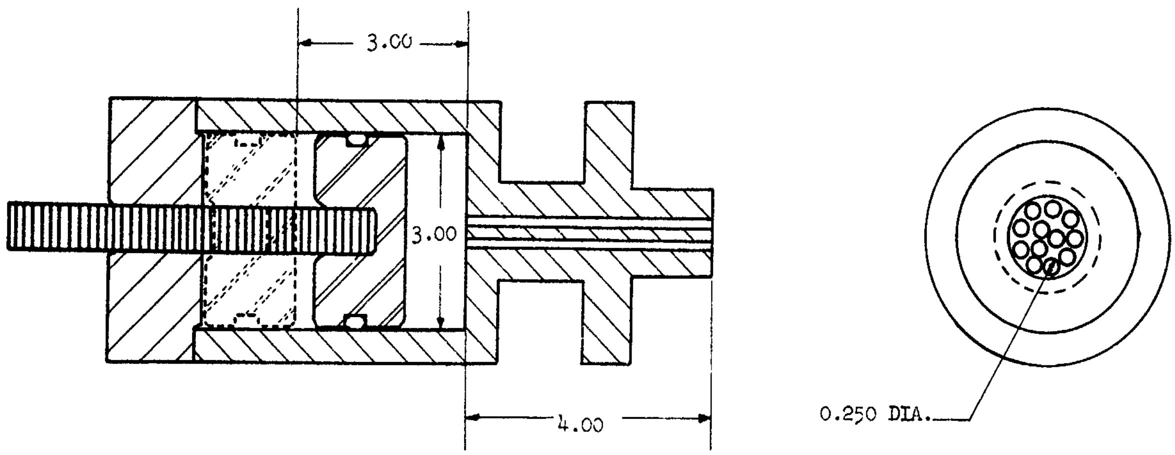

Figure 29. Resonator Design

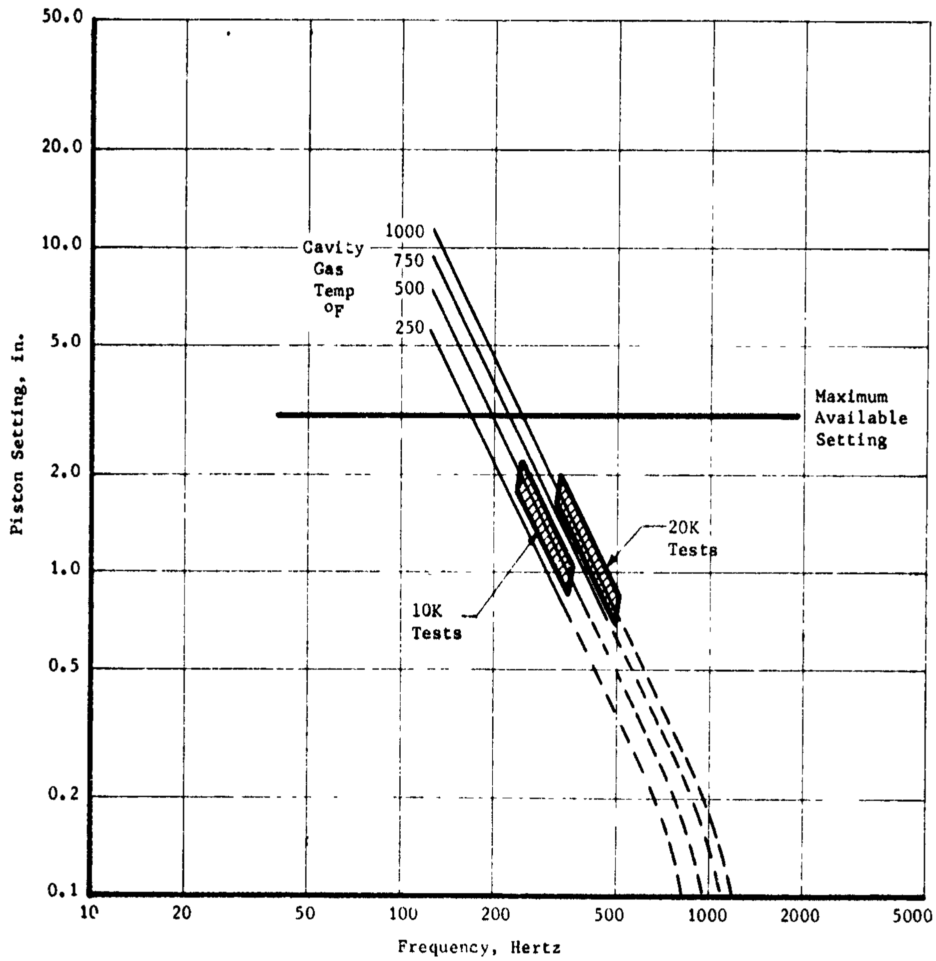

Figure 30. Resonator Piston Stroke vs Frequency

VI, D, Test Data Analysis (cont.)

(U) Twelve holes were used instead of eight to provide peripheral data for establishing the required size of the resonator. The testing approach was to first establish stable operation with the 12-hole configuration, and then to progressively close off holes (and at the same time proportionally reducing the resonator volume) until the lower operating limit was reached. Required resonant cavity volume settings for the twelve-hole configuration were calculated using the Helmholtz resonator equation based on the observed combustion temperatures and frequencies during the test program. These results are shown in terms of piston stroke in Figure 30.

(U) The Helmholtz equation applies to this type of device, provided that the maximum dimension is limited to one-eighth of a wavelength of the pressure oscillation. Beyond these dimensions, the resonator approaches a "quarter-wave resonator". In this region, the Helmholtz resonance equation is no longer valid for predicting the necessary cavity volume. The solid lines on Figure 30 indicate the necessary piston setting (distance from piston face to the end of the cavity) for varying gas conditions and frequency. The dashed lines indicate extrapolations of these operating curves beyond applicability of the Helmholtz equation. As such, they are only estimates of the expected operating conditions. The vertical asymptotes are the resonant frequencies of the resonator with the acoustic cavity volume completely closed by the piston. These frequencies are determined by considering the resonator as twelve quarter-wave resonators rather than twelve Helmholtz resonators.

(C) The resonator was evaluated in tests SP-30-158 through -194. In the first 11 tests, the piston stroke was varied between 1.00 and 0.625 in. Stable operation was achieved at settings of 0.625 and 0.650 in.; however the cavity volume proved very sensitive, with unstable operation occurring at a setting of 0.600 in., a 4% change. With stable operation achieved,

8 of the 12 holes were closed off, and the 4-hole configuration evaluated. Piston stroke was varied between 0 and 0.4 in. in six increments; operation was unstable in all cases. An 8-hole configuration was next evaluated, with similar results. Testing with the 12-hole resonator was then resumed with an attempt to repeat the previously stable test at the 0.625 in. setting. Operation was unstable. The stroke setting was then incrementally varied between 0.425 in. and 1.00 in.; the unit continued to be unstable throughout this range. This concluded the resonator test series.

(C) It was concluded that the resonator cavity volume was insufficient to stabilize the system. The limited success achieved with the 12-hole configuration indicates a marginal condition. Furthermore, the demonstrated criticality of the cavity volume for producing stable operation precludes the effective use of this resonator over the relatively wide thrust range in which it must operate with the MIST engine (5K - 18K). Each specific thrust level has a different combustion temperature and attendant combustion frequency; therefore, an effective resonator must have a broad tolerance on required cavity volume if it is to be effective. Theoretically, the resonator size could be increased to produce this result; however, a larger resonator cannot be integrated into the existing engine design without major packaging change (8-hole configuration maximum possible with existing design).

VII. CLUSTERED SEGMENT TEST PROGRAM

A. SUMMARY

(U) The objective of the clustered segment test program was to evaluate the operation of ten injector segments installed within a common housing simulating the primary combustor configuration of the MIST engine. The testing approach was to evaluate injector operation at several discrete equivalent thrust level operating points between 5K and 50K, with a program goal of demonstrating continuous step throttling over the full 10:1 range.

(C) The test program was initiated on 24 September 1969 and concluded on 3 December 1969, during which period 22 tests were conducted between the 10K and 37.5K operating points. Test data and results are summarized in Table II. At the 10K thrust level, low frequency pressure oscillations of the type encountered in the segment test program were noted, a condition not unexpected. A continuous step throttling test was conducted at the 10K, 12K, and 15K thrust level to establish the lower limit of stable operation. Results showed operation at the 12K level to be marginally stable, with completely smooth operation occurring at the 15K level. Operation at the 25K thrust level was excellent, with no anomalies occurring. The highest equivalent thrust level to which the assembly was tested was 37.5K. At this thrust, minor erosion occurred in one of the ten combustion chambers. A posttest evaluation determined that the injector segment feeding the damaged portion of the chamber had an uneven mixture ratio profile across its face area, which produced a local gas hot enough to cause erosion. Limitations of program funds precluded further testing in the program.

(C) Primary combustor performance was excellent at all thrust levels; in the clustered configuration, c* values were in close agreement with those obtained in the segment program, usually slightly higher. Also, combustion was very smooth at all levels above the "chugging" threshold, with chamber pressure oscillations being $\pm 1\%$ of average chamber pressure.

(U) A discussion of the test facility and setup used in the clustered segment test program is given in Section VII,B. The detailed test program is discussed in Section VII,C. An evaluation of the test data including performance, stability, and the special investigation performed to determine the injector mixture ratio profile is presented in Section VII,D.

B. TEST SETUP

(U) The clustered segment test program was conducted in the H-3 test facility at Aerojet's Sacramento facility. The test system consisted of propellant pressure intensif' -s to deliver high pressure (6300 psia) N_2O_4 and A-50 propellant, a computer controlled servo-mechanical flow control system for transient and steady-state pressure control, primary combustor test hardware, an exhaust gas water scrubber emission control system, and necessary controls and instrumentation to operate the system remotely from a control room located some 100 yards from the test facility. A photograph showing the test hardware installation is given in Figure 31.

(U) The propellant pressure intensifier system is shown schematically in Figure 32. This system consists of single-stroke positive displacement pumps having a 5 to 1 compression ratio. The low-pressure side utilizes compressed nitrogen gas supplied through the flow control system from a high pressure (3000 psia) nitrogen cascade. The 5 to 1 area ratio on the piston allows the prescribed compression ratio to be obtained. The high pressure propellants are then fed through a series of lines and valves to the test hardware.

(U) Pressure control is maintained by servo-operated flow control valves at the intensifier gas side entrance. Four-in. and 2-in. poppet valves are arranged in parallel to give flexibility to the test operation. Servo control is established through a closed loop feedback system using a

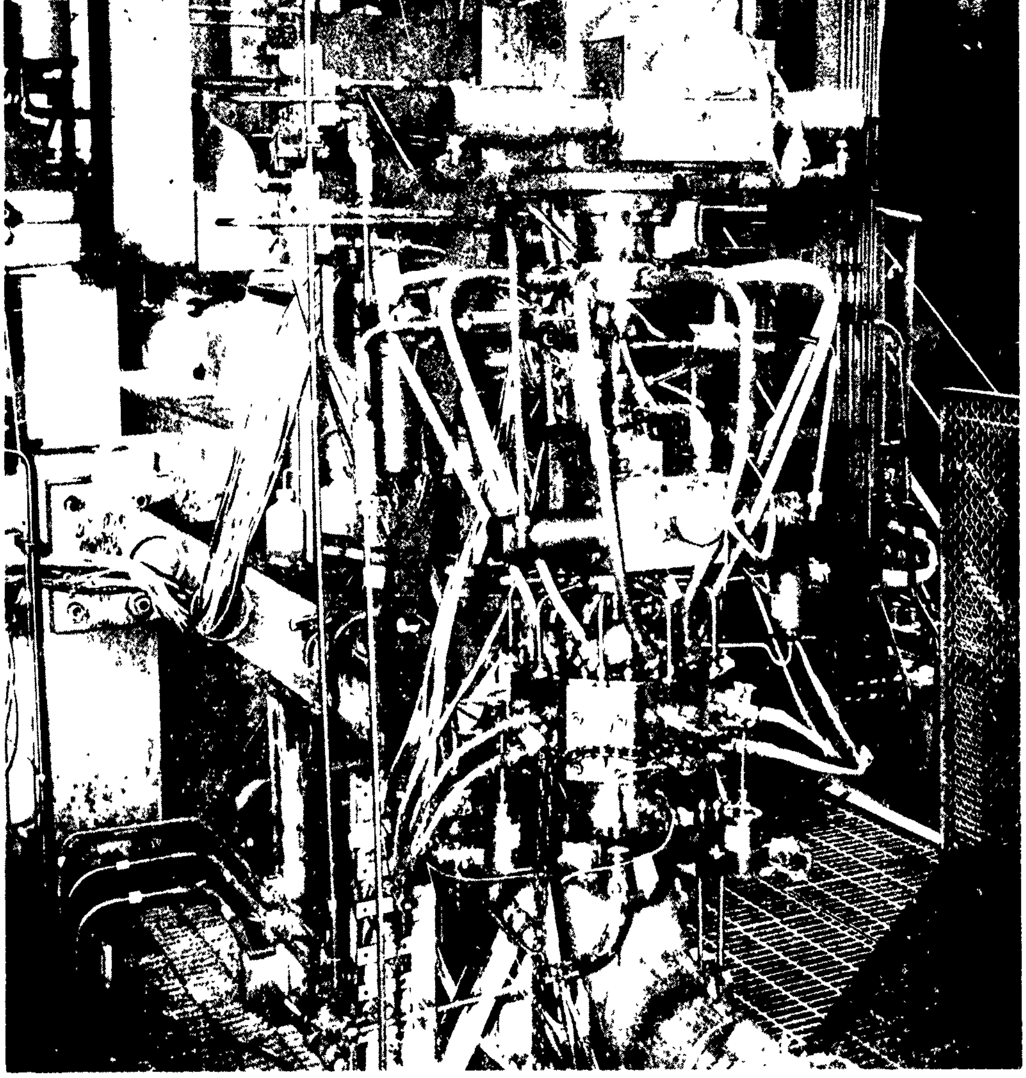

Figure [illegible] Test Installation

[illegible]

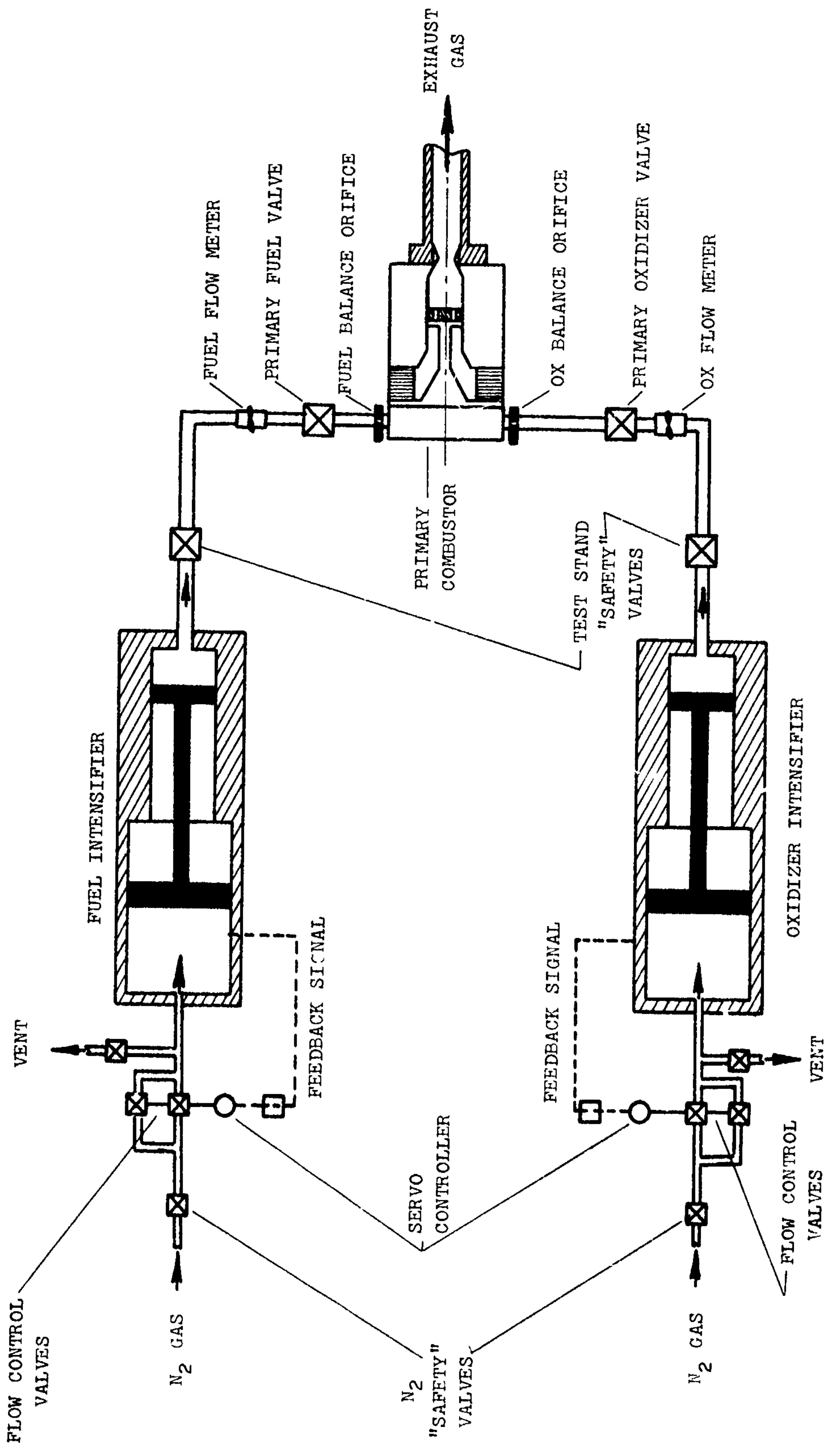

Figure 32. Intensifier Schematic (H-3)

VII, B, Test Setup (cont.)

Pace TR-48 analog computer. This feedback control system continuously monitors the intensifier pressure and compares it to pre-programmed pressure versus time relationship, making corrections with the flow control valves as necessary. This system maintains pressure control for start and shutdown transients, steady-state operation, and continuous throttle feed system pressure changes.

(U) The operating control system consisted of a series of in-line valves for flow sequencing, pressure venting, and propellant pushback feed line draining. These valves were operated remotely from the control room at the test firing console and their operation monitored in the TR-48 computer for malfunction detection. In addition, several other malfunction detection systems are employed. Propellant phasing valves opening rates were checked against a prescribed position at a given time. Propellant overpressure was monitored for shutdown to prevent damage to critical components. The pressure intensifier piston position was monitored to prevent oxidizer propellant exhaustion to the combustor, a condition which would produce an adverse mixture ratio shift. Mixture ratio was monitored through a comparator in the computer which was programmed to terminate the test in the event an adverse mixture ratio developed.

(U) Thermocouples placed at the turbine simulator exit to each compartment were continuously monitored to indicate adverse temperatures in any of the 10 combustors. Temperature limits used were 1500°F for the low thrust tests and 1800°F for the high thrust tests. A combustion stability monitor was used to identify undesirable frequencies and amplitudes in the combustor. A fuel-to-oxidizer feed system pressure comparator was incorporated to insure that the fuel and oxidizer intensifiers were operating properly. All the malfunction devices were patched into the normal shutdown signal sequence in the event any of the functions were beyond pre-programmed limits.

VII, B, Test Setup (cont.)

(U) Standard test instrumentation included Taber transducers for pressure measurement, chromel-alumel thermocouples for temperature measurement, and Potter turbine - type meters for flow control. In addition, the test hardware was monitored with special instrumentation, the locations of which can be seen in Figure 18. An external view of the instrumentation ports and bosses can be seen in Figure 33. The propellant manifold pressures of four of the ten injector segments were instrumented, two with standard Taber transducers and two with high frequency Microsystems transducers. Chamber pressure was measured by one Taber transducer and one flush mounted, high frequency Photocon 307. Microsystems high frequency transducers were also located in the propellant feed system to obtain data on feed system coupling effects. Combustion chamber temperature in each chamber segment was measured by 0.040-in.-dia chromel-alumel thermocouples. These ten thermocouples were located just downstream of the turbine simulator plate opposite the flow orifices. Data from these thermocouples were used to establish the combustion temperature spread between compartments.

C. DETAILED TEST PROGRAM

(U) The test program consisted of five test series, which defined the combustor's operating characteristics at low, intermediate, and high throttle points. Each of the test series are discussed in chronological order in this section; consolidated performance and stability discussions for the entire program are presented in the following section. The test conditions, objectives, and results for the clustered segment test program are summarized in Table VIII. The data summary for all tests is given in Table II.

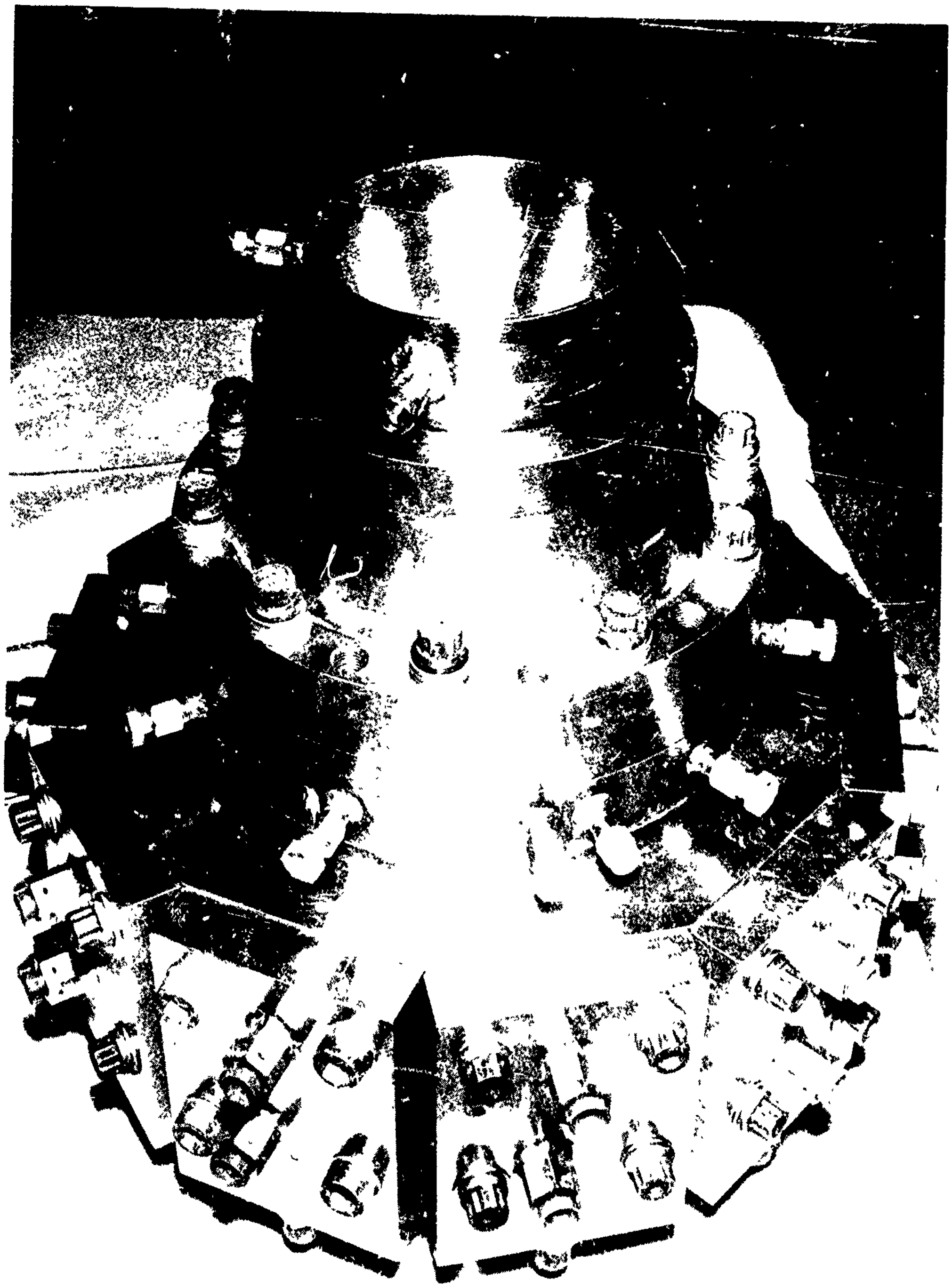

Figure 35. Test Hardware Assembly

TABLE VIII

TEST CONDITIONS AND OBJECTIVES - CLUSTER PROGRAM (U)

SERIES	TEST	TEST CONDITIONS					
	1298-D01-0J	THRUST LEVEL lbs_f	CHAMBER PRESSURE psia	MIXTURE RATIO O/F	DURATION sec.	OBJECTIVE	RESULTS
I	001	22K	1000	30.0	.763	Start transient, controls and feed system checkout to intermediate chamber pressure.	Satisfactory checkout, no hardware damage.
	002	22K	1642	18.3	1.012	Check system balance, performance and stability on minimum duration test.	Satisfactory test, no hardware damage all systems performed as desired.
	003	22K	1675	13.7	3.013	Performance demonstration for extended duration.	System completed prescribed duration. Gross damage sustained to all hot gas system hardware.
II	004	22K	1668	19.9	1.007	Combustor checkout at mixture ratio below exothermic ignition temperature.	Satisfactory modified system checkout test. No hardware damage.
	005	22K	1716	17.4	1.064	System checkout to duration at which combustor erosion was evidenced on Test 003.	Erroneous mixture ratio shutdown at 1.07 seconds. Slight erosion evidenced at baffle insert point between injectors.
	006	22K	1153	24.3	.911	System checkout with welded baffle configuration.	Shutdown at .91 seconds due to incorrect MR setting. No damage.
	007	22K	1723	19.8	1.107	Repeat Test 006	Satisfactory test, no hardware damage.
	008	20K	1692	18.0	1.511	Repeat Test 005	Satisfactory test, no hardware damage.
	009	22K	1698	18.8	2.010	Extended duration performance demonstration.	Satisfactory performance test, completely stable, no hardware damage.
	010	22K	1693	17.1	1.252	Extended duration mechanical integrity check.	Premature shutdown at 1.25 seconds due to primary combustor fuel valve micro switch breakage. No hardware damage.
	011	22K	1709	18.5	2.000	Repeat Test 010	Maximum TTi shutdown at 2.0 seconds. Inspection revealed TTi-10 had failed mechanically. No hardware damage.
	012	22K	1728	18.8	3.007	Repeat Test 010	Completed scheduled duration with no hardware damage.

TABLE VIII (cont.)

SERIES	TEST	TEST CONDITIONS					
	1298-D01-OJ	THRUST LEVEL lbs_f	CHAMBER PRESSURE psia	MIXTURE RATIO O/F	DURATION sec.	OBJECTIVE	RESULTS
	013	22K	1722	20.6	5.005	System demonstration at 5 second duration.	Completed scheduled duration with no hardware damage.
	014	22K	1716	19.4	9.998	Full duration demonstration at 22K thrust level.	Satisfactory test. No hardware damage. Excellent performance and completely stable.
III	015	10K	689	21.3	2.004	System checkout at 10K thrust level.	Completed scheduled duration. Low frequency chugging instability evidenced beyond acceptable limits. No hardware damage.
	016	10K 1 K 15K	660 860 1090	23.0 22.0 21.0	2.999	Three thrust level step throttle test to define minimum stability limit. (10K, 12K & 15K)	Low frequency instability eliminate between 12 & 15K. No hardware damage.
	017	15K	1079	22.7	3.005	Minimum throttle demonstration at 15K thrust.	Satisfactory test completely stable. No hardware damage.
	018	15K	1092	20.7	9.298	Full duration demonstration and minimum throttle operation.	TTi shutdown c 9.28 seconds. hardware inspection denoted slight burning off injector face on side walls in compartments 9 and 10.
IV	019	25K	1290	--	0.915	System checkout at 25K with outboard fuel orifice modification to injectors.	Erroneous MR shutdown at .91 seconds due to low gain from oxidizer flow meter. No hardware damage.
	020	25K	2004	17.7	3.002	Repeat Test 019	Satisfactory 25K demonstration test, no hardware damage, completely stable.
	021	37.5K	3347	12.3	1.402	System checkout at 37.5K thrust level.	Premature shutdown at 1.4 seconds due to transient mixture ratio excursions as sensed on oxidizer to fuel feed pressure comparator. Hardware inspection revealed slight erosion at 5 turbine simulator orifices.
	022	37K	3267	12.9	1.809	Repeat Test 21	TTi shutdown at 1.809 seconds indicating excessive temperature in compartments 9 & 10. Severe throat erosion noted.

VII, C, Detailed Test Program (cont.)

1. Test Series I - 20K Thrust Level Evaluation, Tests 1298-D01-OJ-001 through 003

(U) The 20K thrust operating point was selected for the initial test series because of the extensive data accumulated in this range during the segment test program. Prior to commencement of the test firings, flow control system checkout tests were performed to obtain desirable flow control characteristics in both the low and high pressure ranges.

(C) The first test 1298-D01-OJ-001, was a partial transient test up to 1000 psia chamber pressure to define the start transient characteristics. Satisfactory operation was obtained with only minor changes required in the starting sequence. Test 002 completed the start transient checkout series, with the system ramped to the steady-state balance point. The primary combustor operated at 1680 psia chamber at a mixture ratio of 14. With start, shutdown, and engine balance verified, the test duration was increased to 3 sec for Test 003. Posttest hardware inspection revealed extensive erosion in the hot gas system and between injector elements. Photographs of the damaged hardware are shown in Figures 34, 35, and 36. The injector faces were not eroded; however, the injectors sustained damage from adjacent burning metal. Test record review indicated satisfactory engine operation up to 1.7 sec after FS_1, at which point burning initiated with subsequent chamber pressure decay due to the eroding throat nozzle. Careful examination of the data, together with a review of the high speed color movies, showed no anomalies of any kind prior to failure. Test hardware review disclosed two distinct areas of burning. The most intense erosion was noted just upstream of the sonic throat, proceeding through the throat and through the elbow just downstream of the sonic throat, proceeding through the throat and through the elbow just downstream of the divergent section, as can be seen in Figure 36. The condition of this area indicated material oxidation and exothermic decomposition of the steel which then continued through the downstream elbow.

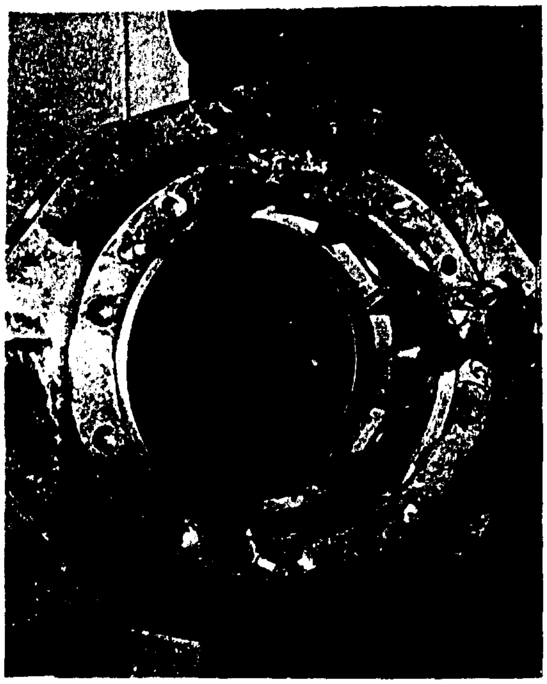

Figure 34. Injector Housing Post 1298-D01-0J-003

Figure 35. Chamber Aft Post 1298-D01-0J-003

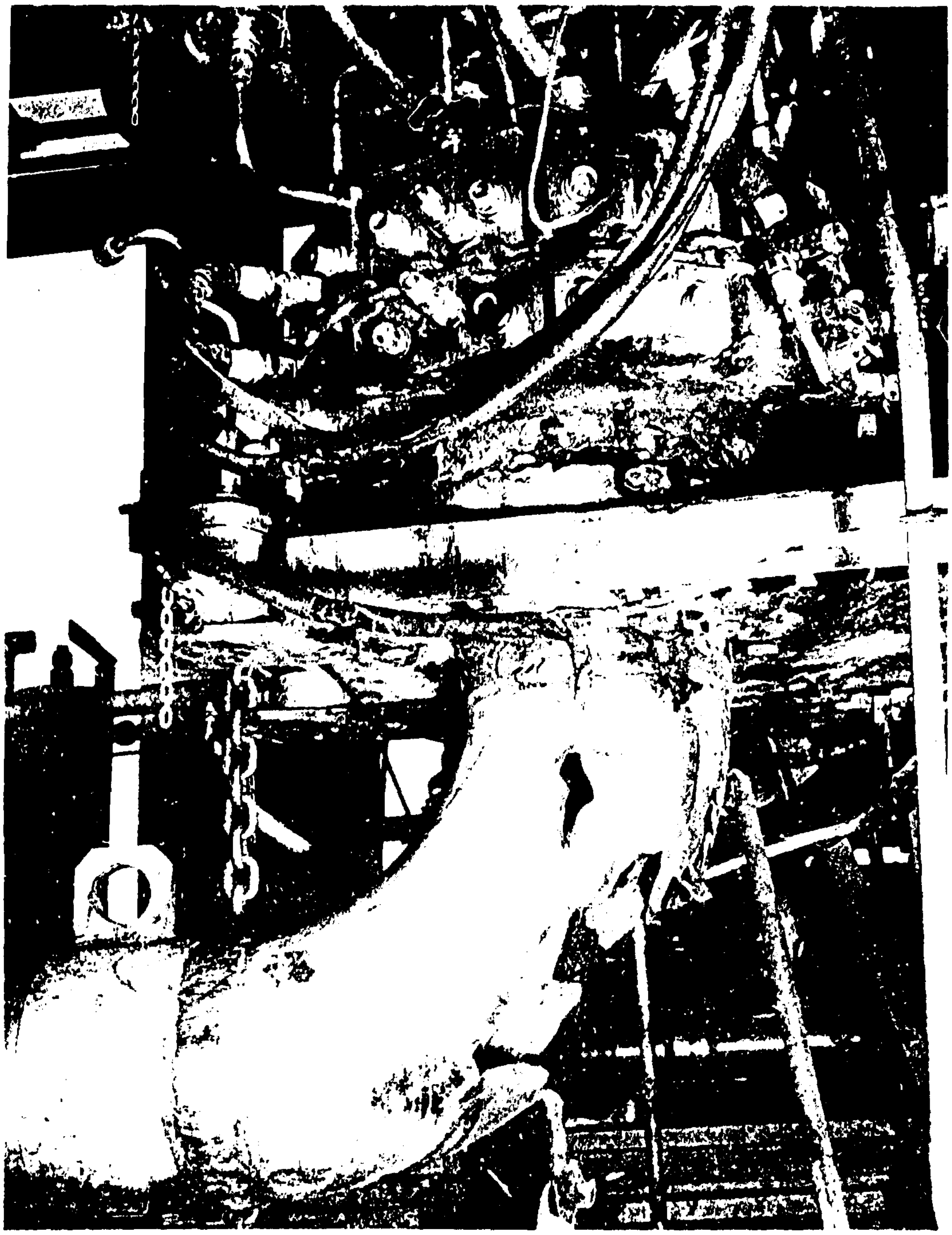

Figure 36. External Test Setup Post 1298-D01-OJ-003

(C) The other burned area, shown in Figure 34, was in the baffle area between the injector segments. Erosion in this area was localized; no gross exothermic burning of the steel had taken place. Cross flow between chamber compartments at the plane of the injector face was postulated as the source of the problem. The primary design was such that the baffles separating compartments are indexed into the upper and lower chamber housings, but not attached to the wall of the injector housing. This left a small gap between compartments at the injector face plane, and it was postulated that any chamber pressure unbalance between compartments could draw unburned quantities of fuel into this area and set up hot recirculation zones. It was also postulated that the problem in the baffle area initiated the burning in the lower portion of the chamber, where there were large recirculation zones due to the irregular shape of the flow passages in that area (see Figure 37).

(C) Prior to resuming the test program, the primary combustor housing design was modified so that the baffles extended into slots machined in the injector housing, thus eliminating the gaps between the chamber sections. Also, a new filler ring was incorporated, which was contoured to provide a smooth transition through the hot gas circuit downstream of the turbine simulator plate. Finally, to further minimize recirculation possibilities, the elbow downstream of the nozzle was replaced by a straight duct leading to a water scrubber system for neutralizing the oxidizer-rich exhaust gases prior to releasing them to the atmosphere. The revised system configurations are shown in Figure 38.

2. Test Series II - 20K Thrust Level Evaluation with Modified System Design, Tests 1298-D01-0J-004 through 014

(C) The test program resumed with Test 004, performed at the same operating conditions as Test 003 except for a higher mixture ratio balance. The test was scheduled for 1.0-sec duration to a steady-state mixture ratio of 20. Programmed duration was achieved and no hardware damage occurred.

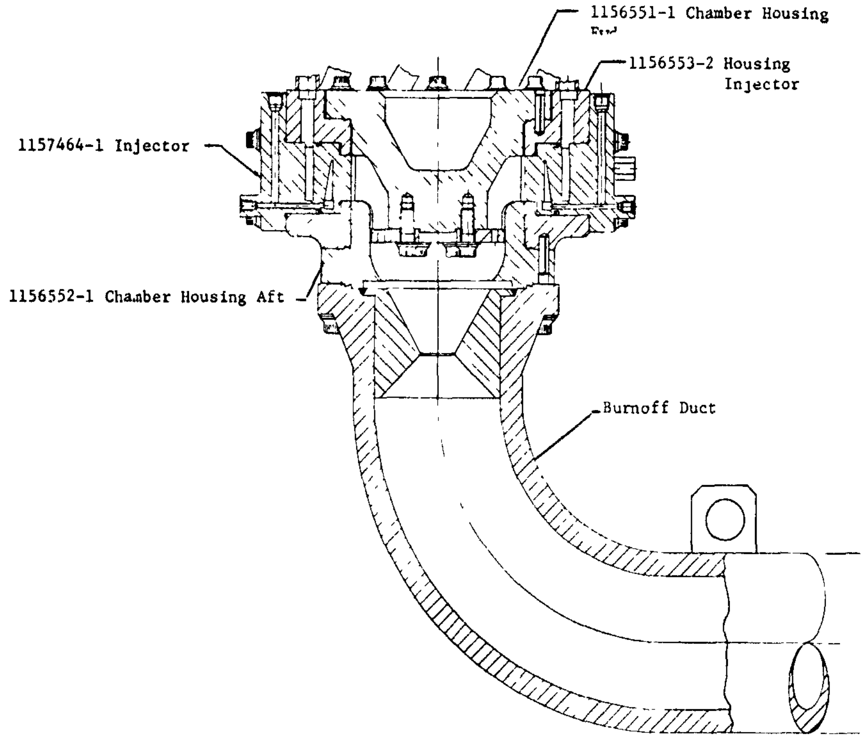

Figure 37. Initial Test Hardware Schematic

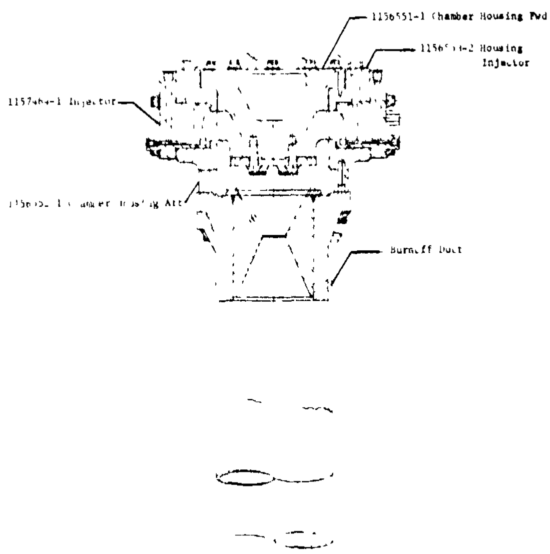

Figure 38. Modified Test Hardware Schematic

VII, C, Detailed Test Program (cont.)

Test 005 was programmed for 1.5 sec duration; the test was terminated prematurely at 1.07 sec by an erroneous signal received from one of the malfunction shutdown circuits. Posttest hardware inspection showed slight erosion of the injector housing at the point where the baffles were inserted into the housing. The cause was attributed to recirculation about the discontinuity at the baffle-housing interface. This discontinuity was eliminated prior to the next test by welding the baffles directly into the housing. Also, thermocouples were installed to measure the gas temperature between the baffle and the housing just downstream of the welded joint.

(C) Tests 006 to 014 were then performed, with test durations incrementally increased during the series. The final two tests were 5 and 10 sec duration, respectively. Posttest analysis of the test records and hardware showed no anomalies. Operation was smooth with excellent combustion performance obtained. The thermocouples installed in the housing prior to the series showed no adverse temperature excursions where burning had occurred on prior tests. The pressure, flow and temperature characteristics during Tests -014 are shown in Figure 39.

3. Test Series III - 10K - 15K Thrust Level Evaluation, Tests 1298-001-0J-015 through -018

(C) Combustor operation at the low throttle levels was evaluated in this test series. The initial test point was programmed for a chamber pressure of 700 psia and mixture ratio of 23, which corresponds to the 10K engine throttle point. The test completed the programmed 2.0 sec duration; no hardware damage occurred. A record review showed an organized low frequency chugging mode in the chamber of 250 Hz at an amplitude of 210 psi peak to peak. This condition was not unexpected, since this throttle level was very close to the lower stable operating range limit established in the segment test program.

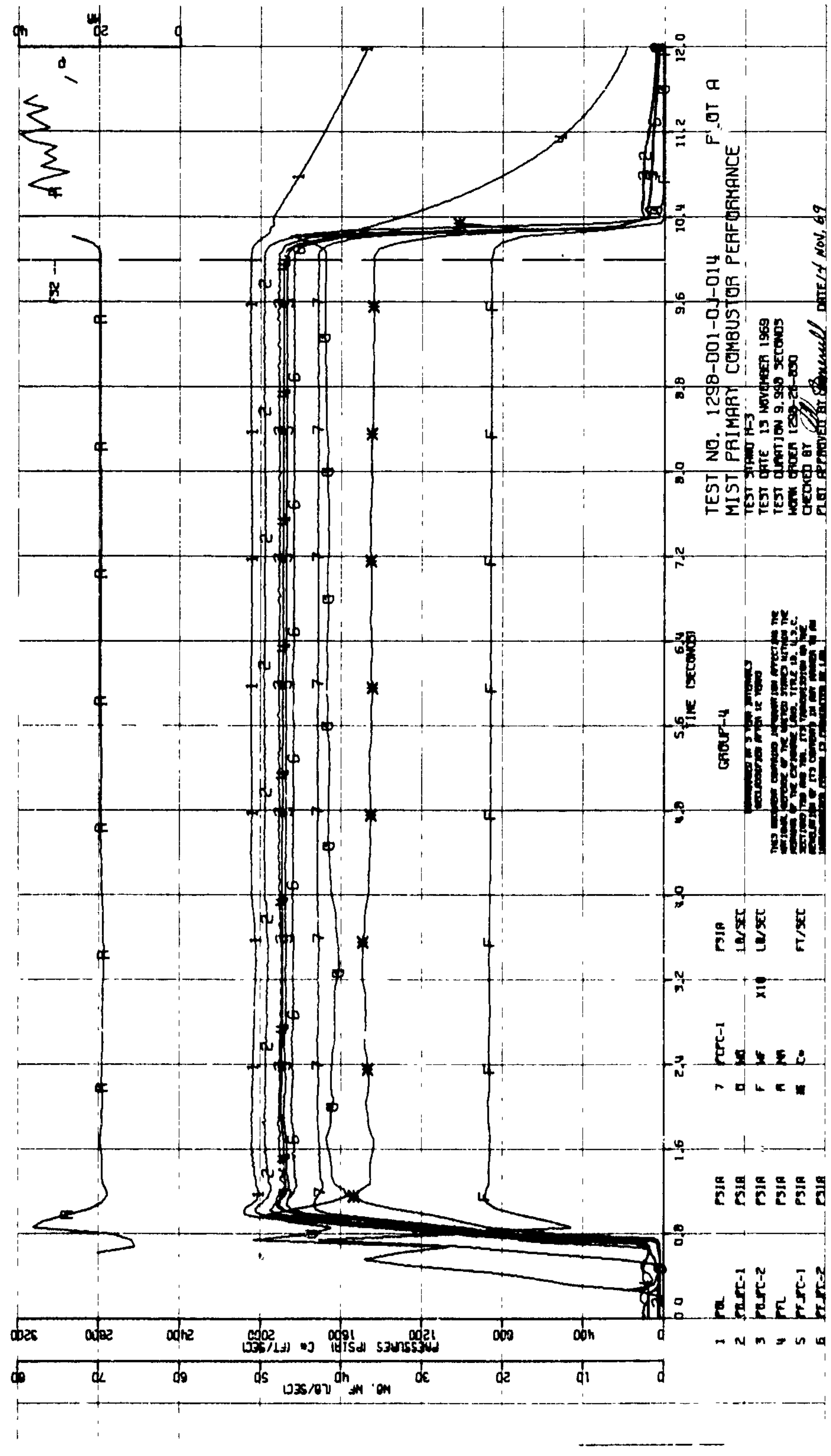

Figure 39. ADR Plot Test 1298-D01-OJ-014 (U)

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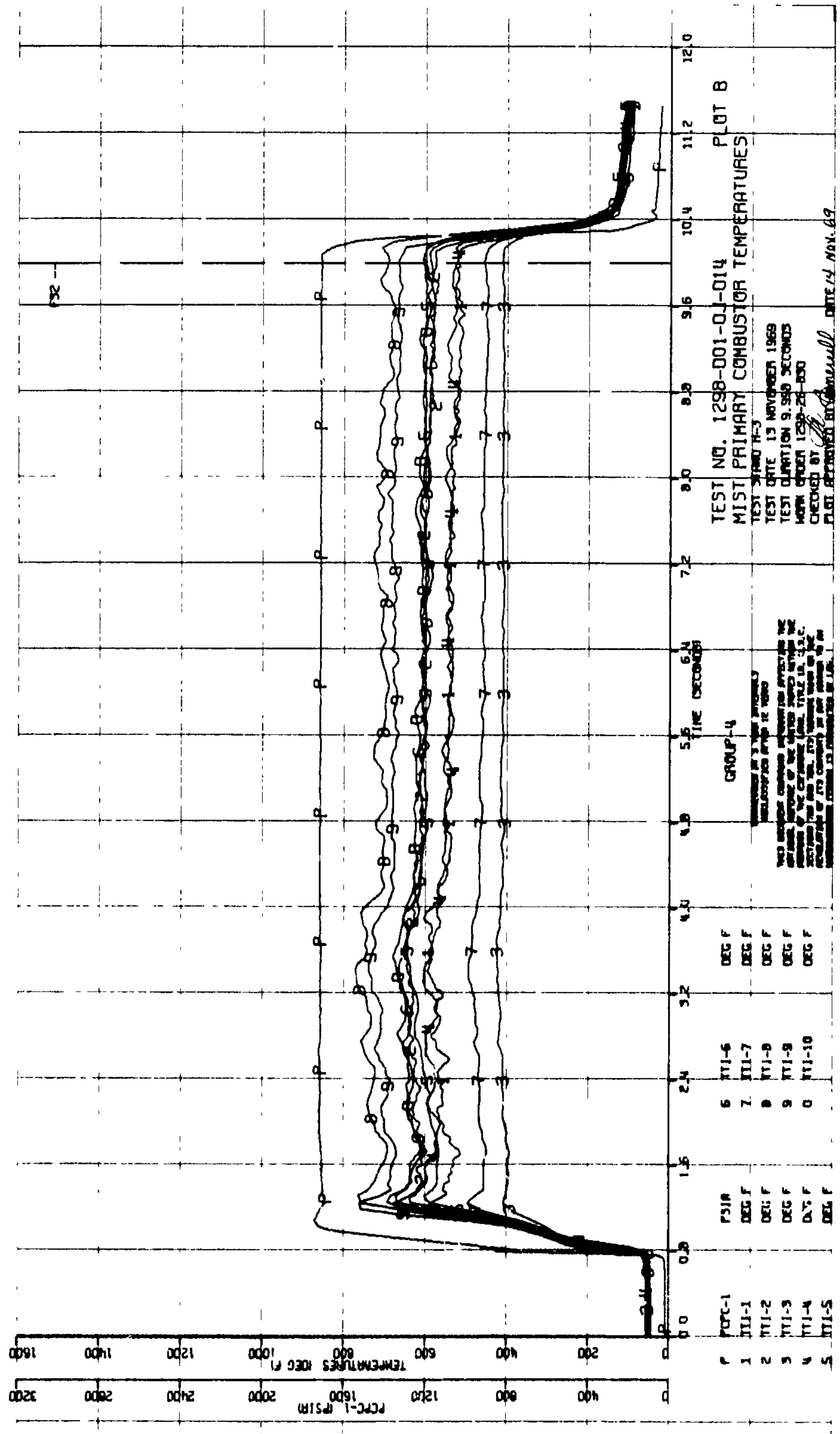

Figure 39. ADR Plot Test 1298-D01-OJ-014 (U)

(Sheet 2 of 2)

VII, C, Detailed Test Program (cont.)

(C) The next test (016) was programmed to ramp the intensifier in step changes at 1.0 sec intervals from 10K to 12K to 15K thrust levels to determine the lower stable operating limit for the cluster hardware. The 3-sec test was satisfactorily completed, with data points obtained at 660, 860, and 1090 psia chamber pressure. No hardware damage was sustained on the test. The three step operation is shown in Figure 40, which gives the pressures, flow rates and mixture ratios throughout the test.

(C) The results of this step-throttle test indicated the combustor attained stable operation between the 12 and 15K thrust levels, with some attenuation noted on the 12K step. The following test (017) was a 3-sec duration evaluation test of the primary combustor operating at the 15K point. Chamber pressure was 1079 psia and mixture ratio 22.7. The next test (018) was a scheduled 10-sec-duration demonstration test at the same balance point. The test was terminated at 9.28 sec by a malfunction detection system which sensed a temperature greater than 1500°F in compartments 9 and 10. Detailed hardware inspection indicated slight erosion on the baffles just downstream of the injector face between compartments 9 and 10. (Injector SN 018 was located in compartment 9, and SN 023 was in compartment 10.)

(C) It was concluded that due to the discrete differences in chamber geometry between the segment and cluster (i.e., converging sidewalls) additional film cooling was required along the cluster chamber wall to provide a cool boundary against the metal parts. Since no injector - chamber compatibility problem had been evidenced throughout the entire segment test program, no film cooling circuit had been designed into the clustered segment hardware. The slight differences in the combustor geometry between the two systems and minor discontinuities at the chamber-baffle joint evidently set up recirculation patterns which allowed uncombusted fuel to reach the wall. To rectify this situation, film cooling was introduced by welding closed

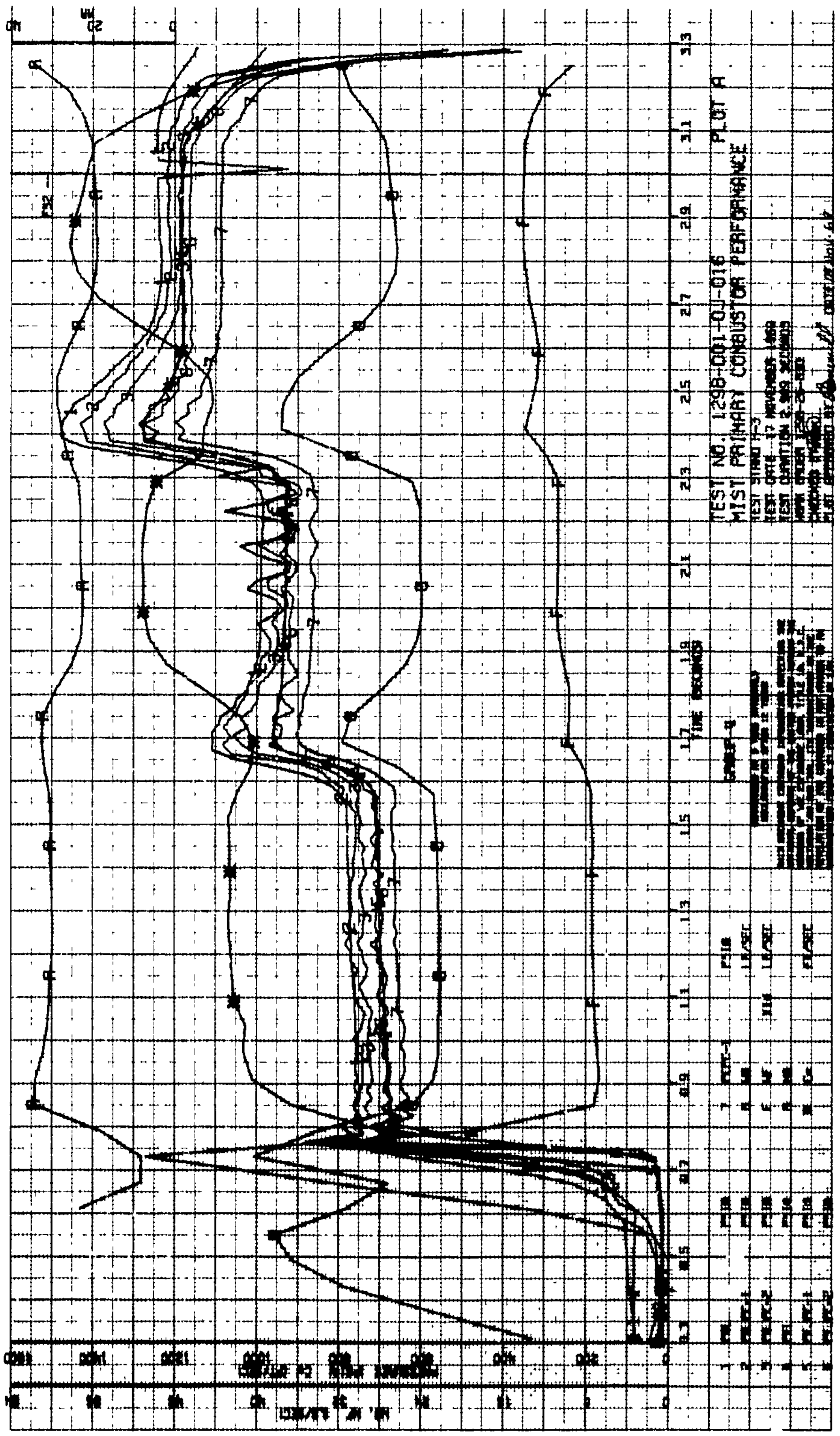

Figure 40. ADR Plot Test 1298-D01-OJ-016 (U)

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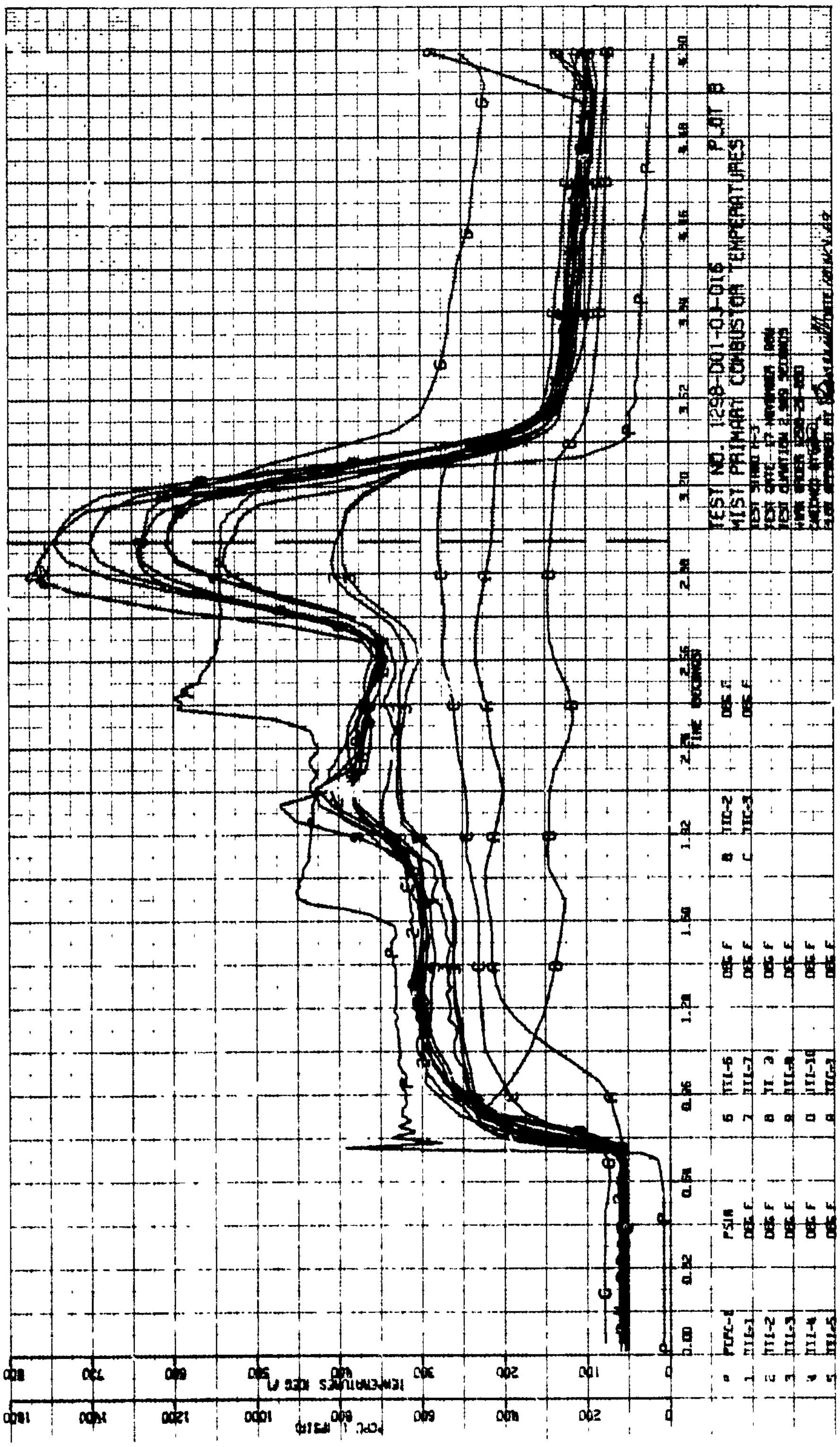

Figure 40. ADR Plot Test 1928-D01-OJ-016 (U)

(Sheet 2 of 2)

the outermost row of the fuel orifices on all 10 injectors, which produced an oxidizer-rich boundary along the side walls.

4. Test Series IV - 25K Thrust Level Evaluation Tests 1298-D01-0J-019 and -020

(C) Using the modified injectors, Tests -019 and -020 were performed at the 25K thrust level. Test durations were 0.9 sec and 3.0 sec, steady chamber pressure during the longer test was 2004 psia; mixture ratio was 17.8. Data and hardware review showed the operation was satisfactory in all respects. The primary combustor operating characteristics during the test are shown in Figure 41.

5. Test Series V - 37.5K Thrust Level Evaluation, Tests 1298-D01-0J-021 and -022

(C) With the satisfactory demonstration at the 25K thrust level completed, the test program proceeded to evaluate operation at the 37.5K thrust level. Engine balance was set for 3350 psia chamber pressure and 12.3 mixture ratio. Two tests were conducted, with durations of 1.4 and 1.8 sec. The first test (-021) was terminated prematurely at 1.4 sec by the fuel-to-oxidizer pressure comparison shutdown device. This device compares oxidizer and fuel pressures measured during the test with preset allowable limits programmed into the computer. Analysis of the test records showed that during the last portion of the transient, there was a momentary fuel-rich condition in the chamber. Postfire hardware inspection indicated very minor erosion on five of the orifices in the turbine simulator plate; the cause of erosion was attributed to the off-mixture ratio transient conditions. The transient was programmed to correct the problem in preparation for the next test.

(C) Test 022 was programmed for a scheduled duration of 3.0 sec; the test was terminated at 1.809 sec by the high temperature shutdown device.

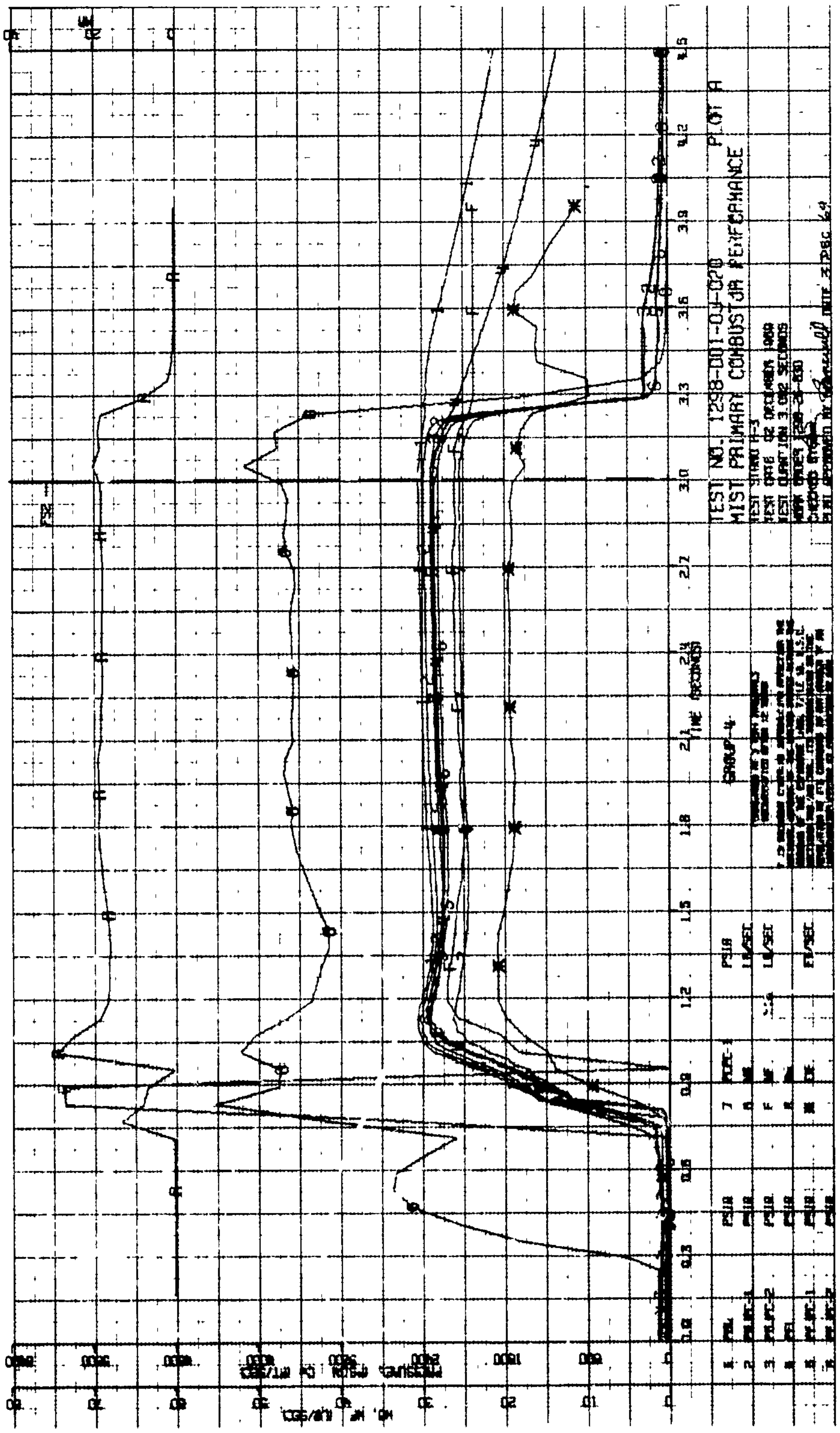

Figure 41. ADR Plot Test 1298-D01-OJ-020 (U)

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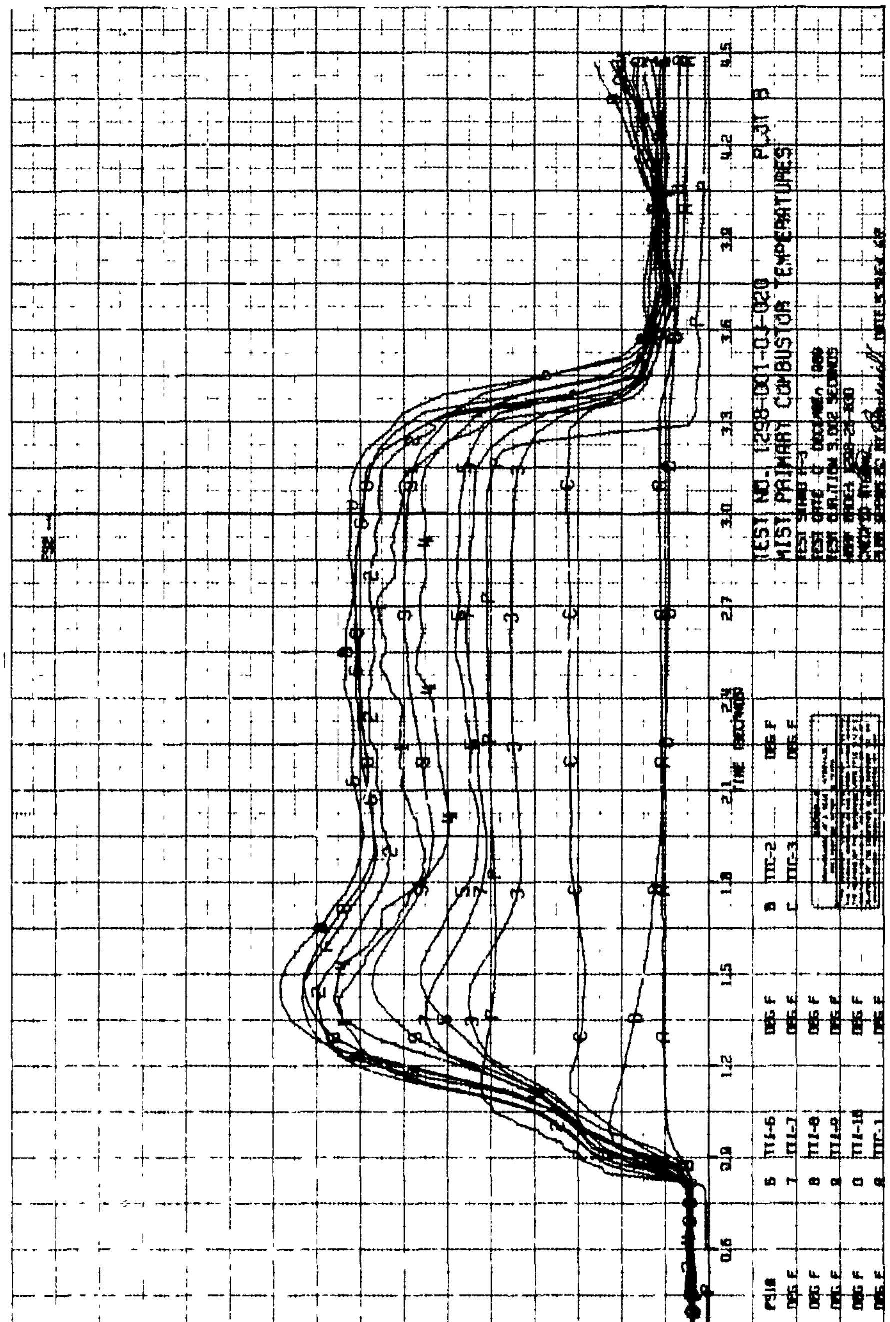


Figure 41. ADR Plot Test 1298-D01-OJ-020 (U)

(Sheet 2 of 2)

Posttest inspection revealed that the outer chamber wall in compartment 10 was eroded downstream of the bottom edge of the injector. The erosion progressed down the chamber wall and through the baffle separating compartments 9 and 10. Photographs showing the damaged areas are given in Figures 42 and 43. The damage occurred in precisely the same circumferential location as previously experienced in Test 018. This fact made the injector feeding the damaged compartment (SN 023) a primary suspect as the cause of the problem. The injector was subsequently removed and its mixture ratio distribution evaluated by cold flow testing along with several other injectors selected at random. The results of this special investigation are discussed in full in Section VII,D,3. It was determined that injector -023 did, in fact, have an uneven mixture ratio profile and that a fuel rich zone was located on the side of the injector where the erosion occurred. It was therefore concluded that the injector was the cause of the problem.

(U) The other injectors also exhibited some maldistribution, but not nearly as severe as that of SN-023. The cause of the maldistribution could be either contamination or the combined tolerance effects of the platelet stack. During the electrical discharge machining operation of the propellant manifolds, some of the removed material is in "flake" form, which can drop into the passages. Subsequent back-flushing may not be 100% successful in removing all particles. In more recent injector designs, special flow paths have been designed into the platelets to allow back-flowing of oil through the propellant manifolds during machining, which precludes contamination from entering the manifold. Such a circuit would be designed into a future MIST injector design. With respect to the combined tolerance effects, the MIST injector is susceptible to some maldistribution from this source because of its very small passage sizes, i.e., 0.002 x 0.010 in. and 0.002 x 0.015 for the oxidizer and fuel circuits, respectively. These small passages were required because the design was based upon laminar flow through part of the throttling range. As determined by the test program, no benefit with respect to stability was derived from the

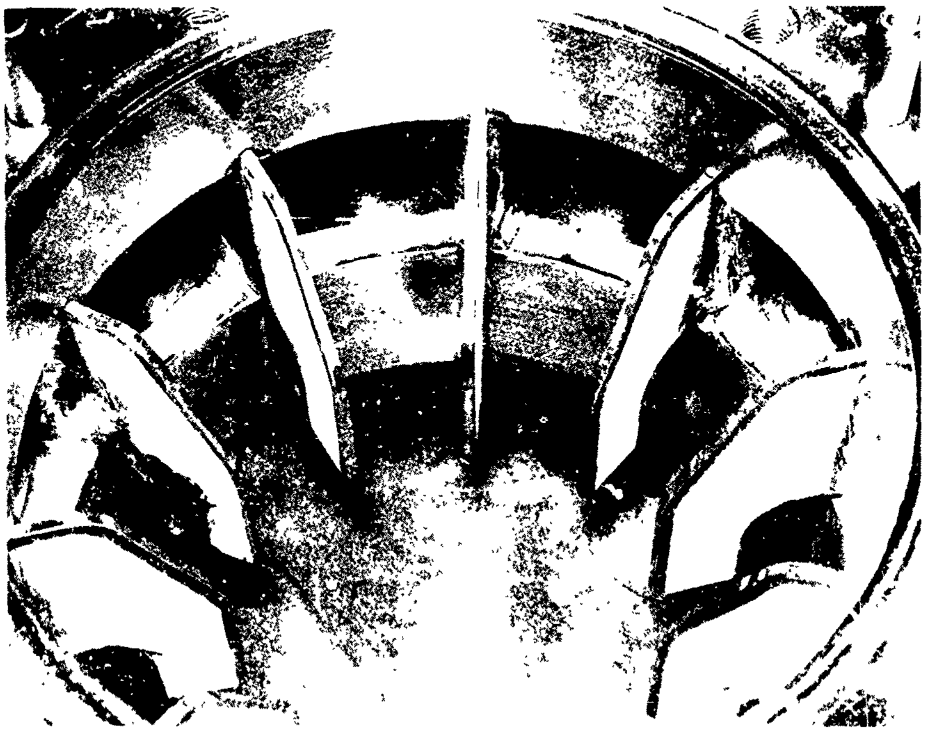


Figure 42. Injector Housing Post 1298-D01-0J-022

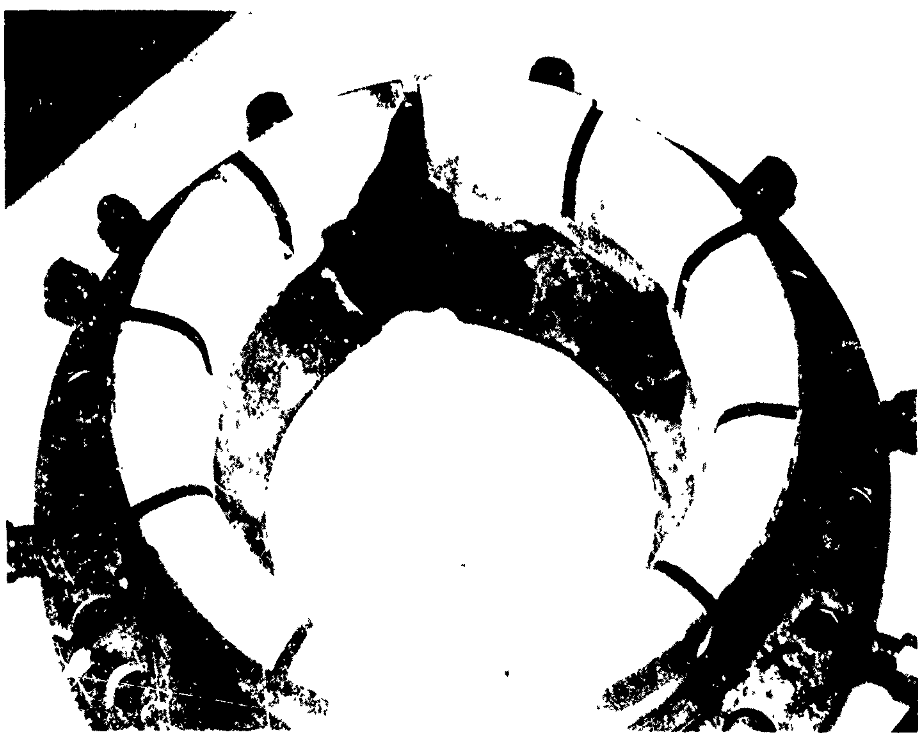


Figure 43. [illegible] Aft Post 1298-D01-0J-022

laminar flow feature (the IO/IF injector, which was the final selected injector, was fully turbulent in the oxidizer circuit); therefore, the passages need not be so small. In future injectors, maintaining passages with a minimum dimension of 0.005 in. are recommended, which should minimize any maldistribution from passage dimension tolerance effects.

(C) The clustered segment test program was concluded at this point because of funding limitations. The only unfulfilled objective of the program was the demonstration at the 50K thrust level. Based upon the successful segment test program results and the overall clustered test program results, it is believed that, following correction of the mixture ratio distribution problem with the injector, this demonstration can successfully be made.

D. TEST DATA ANALYSIS

1. Performance

(U) Performance analysis of the MIST clustered primary combustor was analyzed with respect to two combustion characteristics. The most definitive parameter is the characteristic exhaust velocity as measured in total by the sonic throat located just downstream of the merging of the segment gases as they exit from each set of turbine simulator nozzles. The second parameter which describes the performance of the clustered assembly are the hot gas temperature measurements taken just downstream of the turbine simulator nozzle in line with each compartment.

(C) The characteristic exhaust velocity performance is in excellent agreement with the data generated during the segment program. This characteristic is shown in Figure 44 with the data points from the 22-test clustered program located just above the impinging oxidizer/impinging fuel injector segment performance. This performance data is calculated using the same technique described in Section VI,D,1. Flow rates were again recorded through the use of "Potter" rotor-type flowmeters. Chamber pressure was measured in one segment of the combustion chamber while propellant manifold pressures were averaged between two segment injector readings. The geometric throat area was corrected for entrance conditions of angle, diameter ratio, and clustered geometry to give representative aerodynamic flow area.

(C) Examination of the data in Figure 44 shows performance of the clustered segments to be generally higher than the single segments over the entire thrust range. This performance increase is believed to be not necessarily a result of higher performance in the clustered version, but rather reflective of differences in the assessment of the two throat geometry flow coefficients.

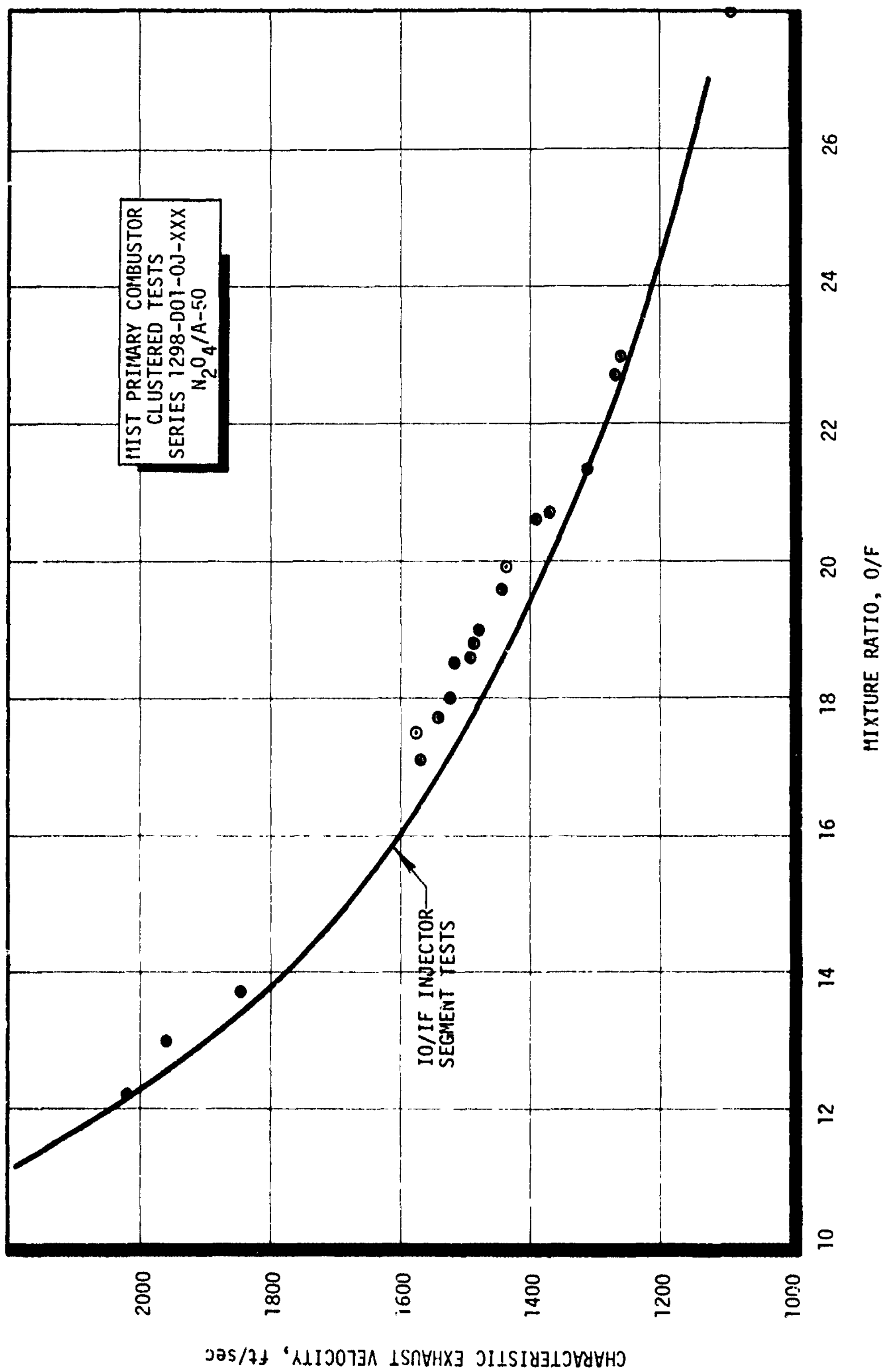


Figure 44. c* vs MR, Cluster Tests (U)

(U) The temperature data for the ten thermocouple readings on each of the 22 tests is included in Table II. An analysis of all valid data is summarized in Table IX. Given are the test number, mixture ratio, theoretical temperature for the test conditions, average measured temperature and maximum temperature spread between thermocouples. Generally, the temperature variation was less than 200°F, well within acceptable engine turbine variation limits. Not included in the results of Table IX are the temperatures indicated by TTI-3 and TTI-7 for Tests -008 through -022 and by TTI-5 for Tests -020 through -022. These thermocouples constantly indicated temperatures substantially below the normal spread. It could be postulated that the injectors opposite these locations were balanced to a higher mixture ratio, thereby producing a lower temperature. However, analysis of the data of Tests -003 through -008 (transient tests) showed that up until Test -008, thermocouples TTI-3 and TTI-5 were not reading low. The precise reason for the sudden change in readings of these particular thermocouples has not been determined; no hardware, instrumentation changes, or changes in test procedure were made at this time. Similarly, up until Test -020, TTI-5 was reading normally. It was concluded that these changes must have been caused by an instrumentation shift, and that the indicated values do not reflect the true temperatures.

(C) It is therefore concluded that the MIST clustered primary combustor performance is both acceptable from an engine operation standpoint and is in excellent agreement with the segment data generated during the segment development portion of the program. Also, it can be concluded that the combustor appears to operate as predicted with good nominal performance although minor chemical incompatibilities were noted on the high thrust testing of the clustered assem' This phenomenon is described in detail in Section VII,D,3.

TABLE IX

TEMPERATURE SUMMARY - CLUSTER PROGRAM

Test No.	Mixture Ratio	Theoretical Partial Equilibrium Temp, °F	Average Recorded Temperature, °F	Temperature Spread, °F
1298-D01-OJ-001	(1)	-	(2)	-
-002	18.3	580	(2)	-
-003	13.7	900	970 (3)	220
-004	19.9	507	(2)	-
-005	17.5	630	(2)	-
-006	(1)	-	(2)	-
-007	19.8	510	(2)	-
-008	18.0	600	678	208
-009	18.8	550	622	183
-010	17.1	660	691	210
-011	18.6	563	645	275
-012	18.8	550	645	141
-013	20.6	475	548	108
-014	19.4	525	611	166
-015	21.3	450	351	54
-016	19.2	535	654	214
-017	23.0	390	402	76
-018	20.7	470	548	180
-019	(4)	-	(2)	-
-020	17.6	620	753	150
-021	12.3	1000	(2)	-
-022	13.0	950	1198	238

(1) Test duration too short to reach steady-state mixture ratio.
(2) Test duration too short for steady-state temperature data.
(3) Only three thermocouples used.
(4) Oxidizer flowmeter malfunction - no valid data.

2. Stability Characteristics

(C) The test data analysis of the cluster tests showed that the stability characteristics for the cluster assembly were generally the same as for the segment assembly with a somewhat closer correlation obtained with segment tests in which the chamber extension was not installed. This is reflected in the comparison of several thrust points noted below. For comparison, only IO/IF pattern injectors were used.

Thrust Level	Segment Program				Cluster Program	
	w/o Chamber Extension		w/Chamber Extension			
	Frequency (Hz)	Amplitude (% P_c)	Frequency (Hz)	Amplitude (% P_c)	Frequency (Hz)	Amplitude (% P_c)
10K	250	± 15.0	Random	± 1.0	210	± 15.0
12K	250	± 14.0			210	± 9.5
15K	280	± 2.2			Random	± 1.2
25K			Random	± 1.0	Random	± 1.0

(U) The segment test setup was substantially different from the cluster test setup; i.e., the propellant feed line lengths varied substantially, no venturis were used in the cluster testing, 10 parallel circuits were employed on the cluster as compared to one on the segment, and there were variations in hardware configuration.

(C) The resulting similarity in level and frequency of the unstable ranges in the two test programs tends to confirm the conclusion that the predominant factor affecting stability is the loop between P_{oJ} and P_c (the "lump" parameter described in Section VI).

3. Special Investigation of Injector SN 23 Following Test 1298-D01-0J-022

(C) In Test 1298-D01-0J-022, chamber wall erosion downstream of injector SN 23 was noted. It was postulated that a locally low mixture ratio could have generated this burning. In order to verify this hypothesis, SN 23 injector and others were cold flowed with trichloroethylene and water under simulated firing conditions. The following paragraphs describe the cold flow testing and interpret the resultant data.

(U) The injector flow fixture and collector (Figure 45) comprise an injector mounting fixture, a flow collection head, and a collection bottle array with interconnecting plumbing. A pneumatically driven deflection plate covers the collection head and prevents liquids from entering the collection bottles during flow startup and shutdown transients. The collection head comprises 100 3/16-in. stainless tubes arranged in a 10 x 10 matrix. The collection tube ends on the inlet side are swaged square and sharpened to ensure maximum recovery of the test fluids. The test fluids are routed through the collection head into individual sample bottles via Tygon tubing. The amount of fluid accumulated in each bottle is measured with a graduated cylinder.

(C) The injectors were positioned symmetrically over the collection head and one inch above it. Trichloroethylene was used as simulant for the N_2O_4 and water simulated the A-50. Test durations were 25 sec, with the water flow rate at 0.19 lb/sec and trichloroethylene flow rate at 2.9 lb/sec. These flows correspond to oxidizer and fuel propellant flows of 3.7 and 0.235 lb/sec, respectively, which corresponds to the 20K thrust operating point. The resulting data, consisting of 100 water and trichloroethylene volumetric measurements, were reduced to engineering terms with the aid of a computer program.

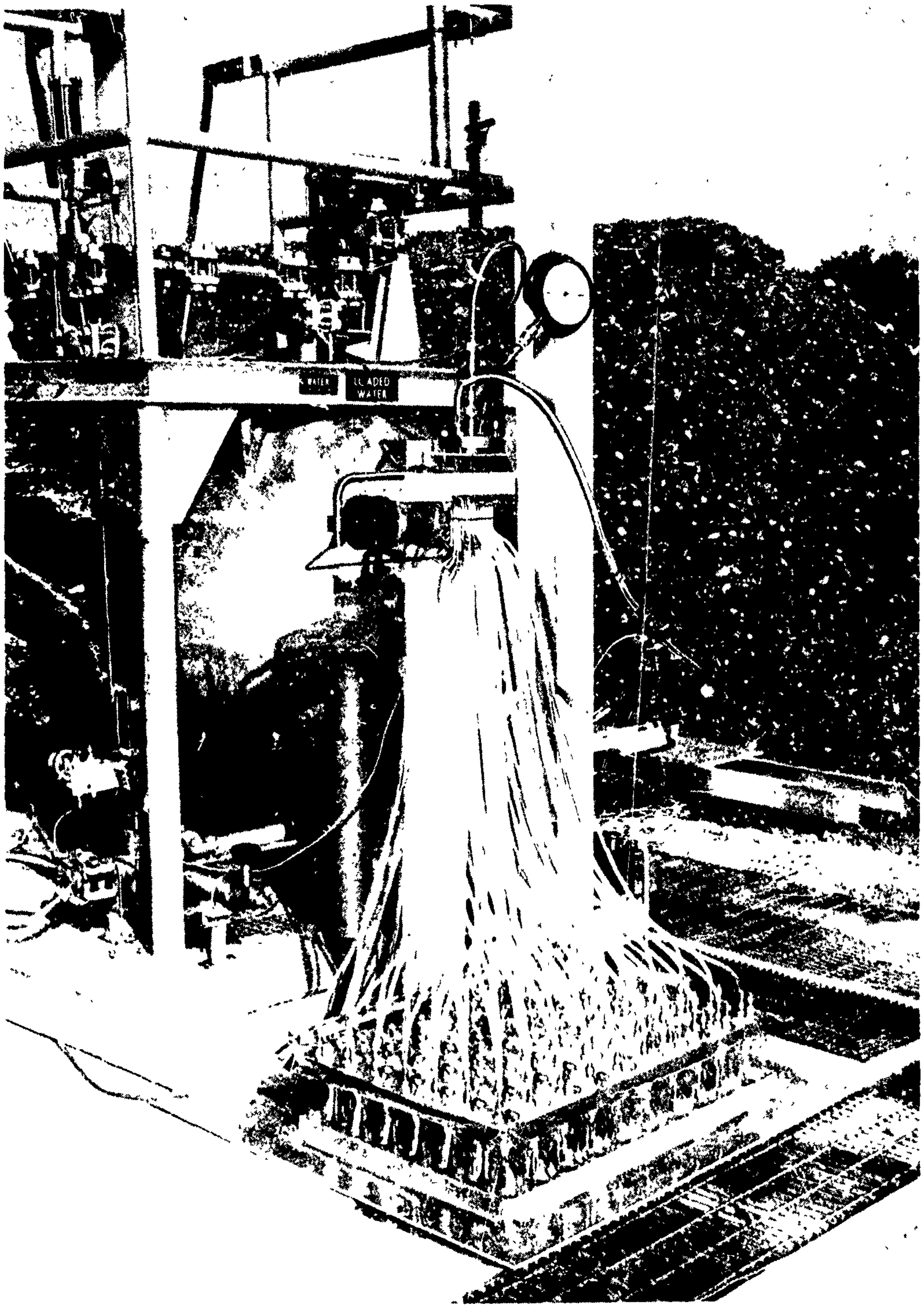
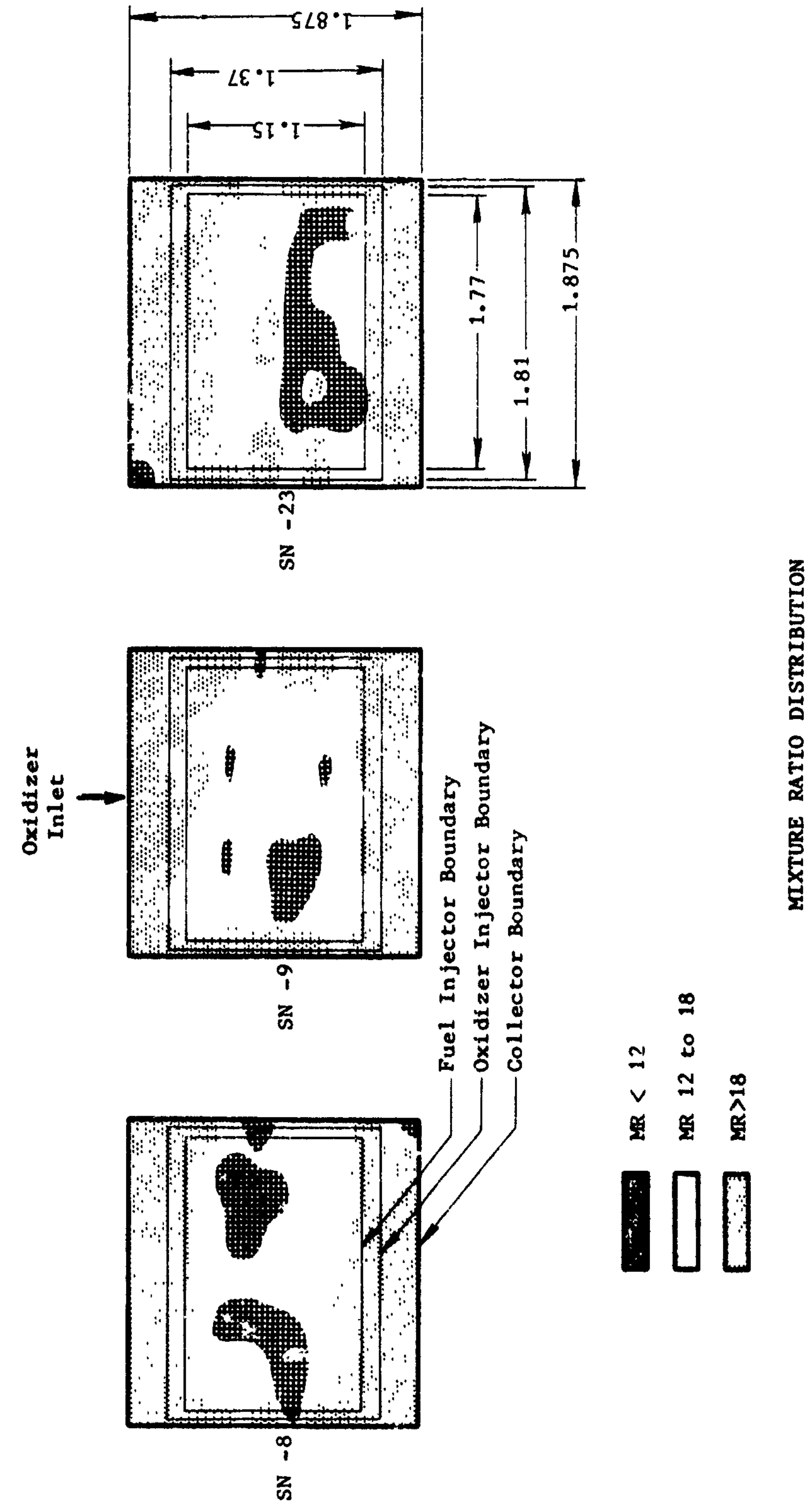


Figure 45. Injector Flow Fixture

(C) The resulting mixture ratio data, corrected to propellant values, are presented for three injectors tested in Table X with a graphical presentation in Figure 46. The data are tabulated as if the injector were above the page, flowing toward the page, with the oxidizer inlet to the left margin. The orientation of Figure 45 is similar except the oxidizer inlet is as noted.

(C) Inspection of Figure 46 reveals some qualitatively similar characteristics. The mixture ratio gradient is oxidizer rich at the boundaries and fuel rich in the center. The majority of the excess oxidizer is located at the top and bottom of the injector with the top being defined as the oxidizer inlet. This zone is generated by the outside row of oxidizer doublets, the location of which is indicated in the figure. In fact, at the edge of the collector, nearly all the flow was oxidizer. At the left and right of the injector, this distribution is not evident. However, it is likely that some oxidizer was not collected at these boundaries, as the oxidizer injection point was very close to the edge of the collector.

(C) Inspecting the individual differences between injectors, it can be concluded that injectors SN 8 and SN 23 had some potential for streaking the chambers. Injector SN 9, however, has a more uniform mixture ratio profile and would not generate hot zones in the resulting combustion gases. One important difference between injectors SN 8 and 23 should be noted, however. The low mixture ratio zone of injector SN 8 is positioned in the center of the injector and is surrounded by the bulk of the remaining high mixture ratio products. It is unlikely, then, that this hotter core would reach the chamber walls. It should also be noted that these distributions will be flattened by turbulent mixing as the products proceed down the chamber. Injection SN 23 had a fuel-rich core located toward the bottom of the injector. Between this core and the chamber wall is distributed approximately 1.5% of the total flow. It is likely, then, that turbulent mixing would not significantly dilute this low mixture zone and the potential for burning the lower chamber wall existed. The burning noted in Test -022 was probably generated by this mechanism.



NOTE: Direction of flow is toward paper

Figure 46. Water Flow Graphical Data

TABLE X

WATER FLOW TABULAR DATA
INJECTOR SN 8

57.60	29.54	25.60	14.93	10.88	17.53	14.08	15.20	47.20	9.60
128.00	29.67	11.68	10.08	12.40	12.62	16.27	13.87	57.60	28.80
46.40	28.34	16.00	10.72	9.80	9.42	13.60	15.20	36.80	24.00
107.20	38.40	15.11	10.72	10.20	8.53	16.60	15.60	20.00	999.00
999.00	51.20	16.16	11.20	13.49	12.44	17.83	16.80	44.00	35.20
129.60	19.73	16.00	12.80	14.86	15.09	16.00	18.93	52.00	43.20
48.00	40.00	16.36	14.04	11.67	14.86	15.68	18.93	73.60	999.00
36.80	32.00	15.42	10.67	10.67	9.02	13.87	12.34	70.44	999.00
99.20	30.77	16.46	16.46	13.87	17.14	8.74	14.60	86.40	999.00
999.00	27.20	12.00	16.40	32.96	11.84	14.80	35.60	46.40	800.00

FUEL INJECTOR BOUNDARY

OXIDIZER INJECTOR BOUNDARY

OXIDIZER INLET

COLLECTOR BOUNDARY

TABLE X (cont.)

INJECTOR SN 9

48.00	35.60	52.62	75.73	11.73	30.40	29.60	16.00	36.80	92.80
40.00	82.40	23.37	14.58	12.48	13.00	12.62	19.43	25.87	48.00
23.20	50.40	14.67	13.80	12.60	12.98	12.07	19.20	1[illegible].80	46.40
60.80	14.40	19.73	11.40	12.48	12.80	13.44	17.00	44.80	999.00
70.40	18.80	18.00	11.56	12.40	12.80	10.24	15.20	97.60	41.60
999.00	35.20	16.71	13.51	9.80	12.44	12.09	17.20	56.00	24.00
999.00	60.00	16.71	11.32	12.80	12.32	12.34	16.40	69.60	17.60
59.20	30.13	15.13	11.20	13.40	9.60	16.46	15.64	71.20	27.20
83.20	15.67	16.00	12.98	15.77	9.73	15.64	17.83	16.80	19.20
104.00	13.67	19.73	23.52	18.70	23.20	31.20	13.87	50.67	60.80

FUEL INJECTOR BOUNDARY

OXIDIZER INJECTOR BOUNDARY

OXIDIZER INLET

COLLECTOR BOUNDARY

TABLE X (cont.)

INJECTOR SN 23

30.40	67.4[illegible]	14.00	31.20	17.69	44.40	27.66	25.80	30.40	22.40
25.07	14.40	38.80	17.14	20.00	13.39	9.71	12.68	49.60	70.40
68.00	64.80	29.87	14.18	16.23	17.52	12.75	11.78	24.00	19.20
37.60	198.40	21.33	13.28	16.53	10.55	13.88	11.65	7.54	19.20
52.80	278.40	25.60	14.93	18.93	11.31	15.27	14.78	34.00	64.00
36.80	67.48	27.52	13.71	18.67	11.59	12.75	12.87	126.40	48.00
21.60	102.40	42.67	12.44	17.33	[illegible]	11.30	12.57	18.40	160.00
25.60	24.00	19.20	16.82	16.00	9.12	23.2[illegible]	10.62	44.80	160.00
41.60	26.29	24.00	16.40	21.16	11.33	9.10	11.68	35.20	320.00
5.71	31.40	18.40	18.13	20.57	13.31	33.42	16.80	11.73	320.00

FUEL INJECTOR BOUNDARY

OXIDIZER INJECTOR BOUNDARY

OXIDIZER INLET

COLLECTOR BOUNDARY

APPENDIX

MIST ENGINE DESCRIPTION

TABLE OF CONTENTS

TABLE LIST

FIGURE LIST

I. DESIGN POINT

(C) The MIST engine is shown in Figure A-1. It is designed for 50,000, lb thrust and 10:1 throttling. Engine characteristics are shown below.

	Nominal Design Point	Throttle 2:1	Throttle 10:1
Thrust, lb	50,000	25,000	5,000
Specific impulse, sec (vac)	337	334	315
Specific impulse efficiency	91.8	91.0	86.0
Mixture ratio	2.41	2.4	2.41
Nozzle area ratio	300	300	300
Minimum suction pressure, psia			
Oxidizer	(22)*	35	4
Fuel	(11)*	14	2
Thrust chamber pressure, psia	2,800	1,400	285
Engine weight, lb	403(442)*	Same	Same

( )* with boost pumps

II. PHYSICAL DESCRIPTION

(U) A cross section of the MIST engine (exclusive of boost pumps) is shown in Figure A-2. The engine consists of a turbopump assembly, a thrust chamber assembly, and fuel and oxidizer suction valves. The MIST engine with boost pumps for low suction pressure capability is shown in Figure A-3 (two sheets). The turbopump assembly includes the main pumps, the turbine, the primary injector and combustor, and the primary combustor fuel control valve. The thrust chamber assembly includes the secondary combustor, nozzle, secondary injector, and the secondary combustor fuel valve.

(U) The turbopump is oriented with its shaft axis in line with the thrust vector. The turbopump is mounted on top of the thrust chamber, with the engine

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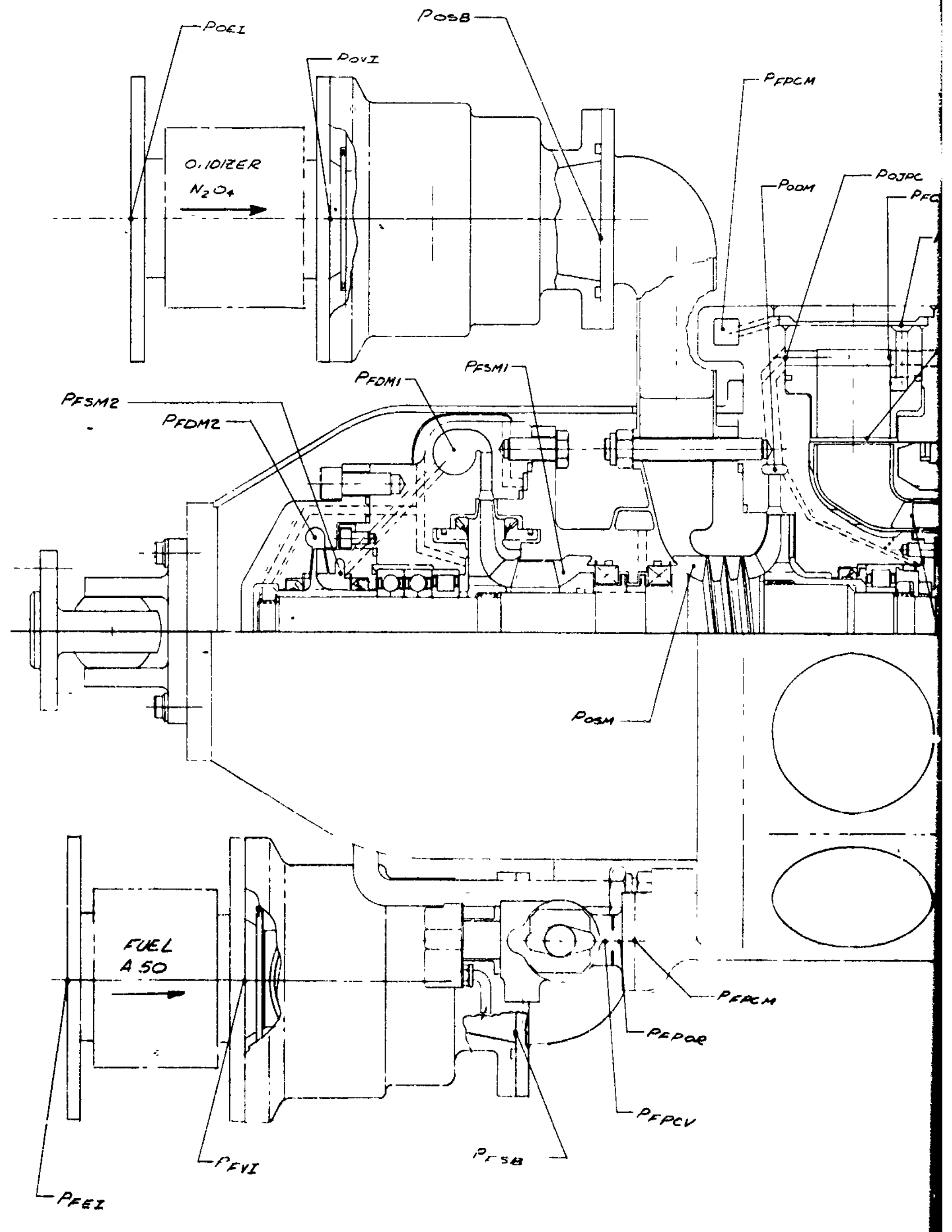

P_{OEI}
P_{OSB}
P_{OVI}
P_{FPCM}
OXIDIZER
N_2O_4
P_{ODM}
P_{OJPC}
P_{FSM1}
P_{FDM1}
P_{FSM2}
P_{FDM2}
P_{OSM}
FUEL
A 50
P_{FPCM}
P_{FPOR}
P_{FPCV}
P_{FSB}
P_{FVI}
P_{FEI}

1

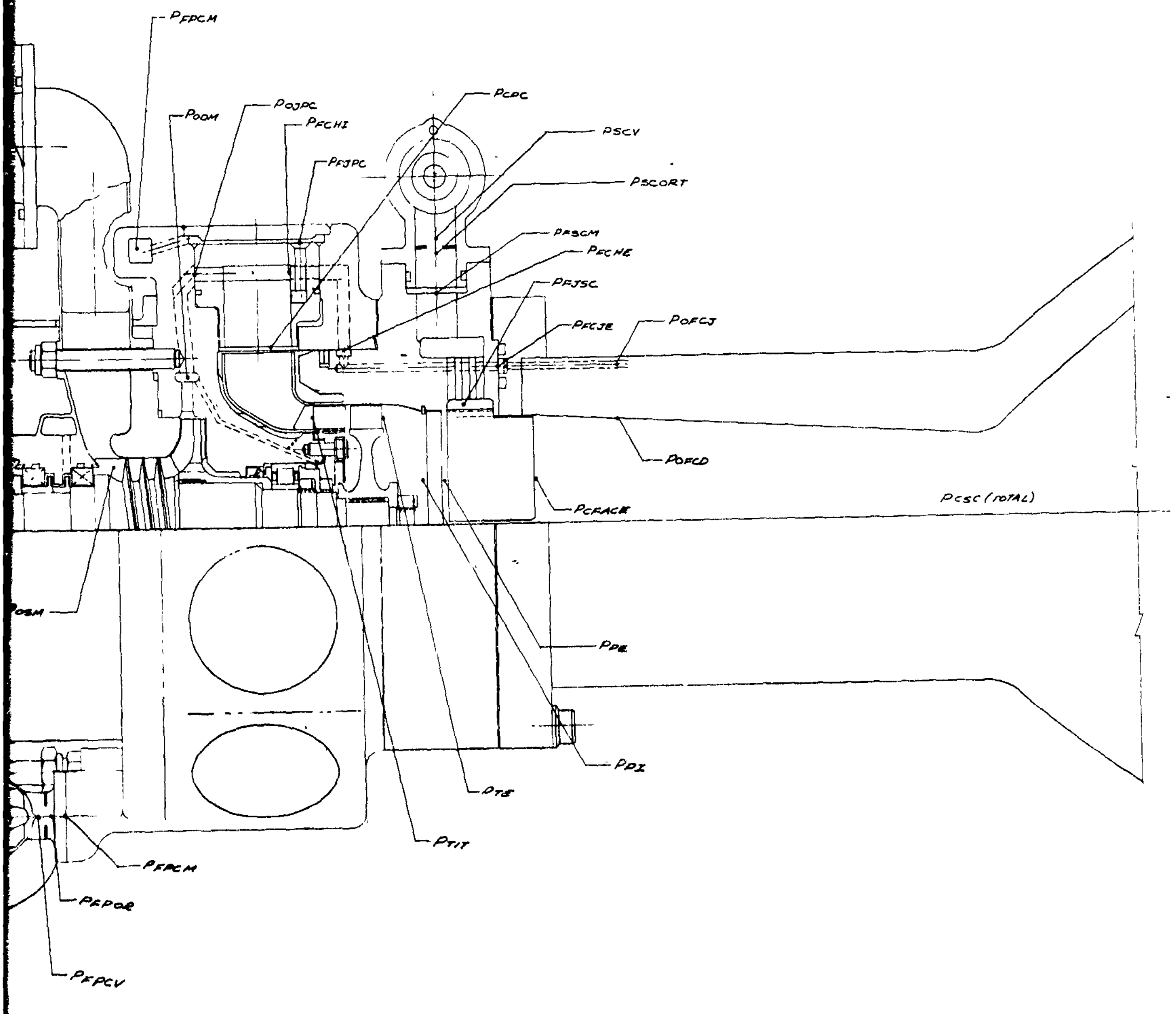
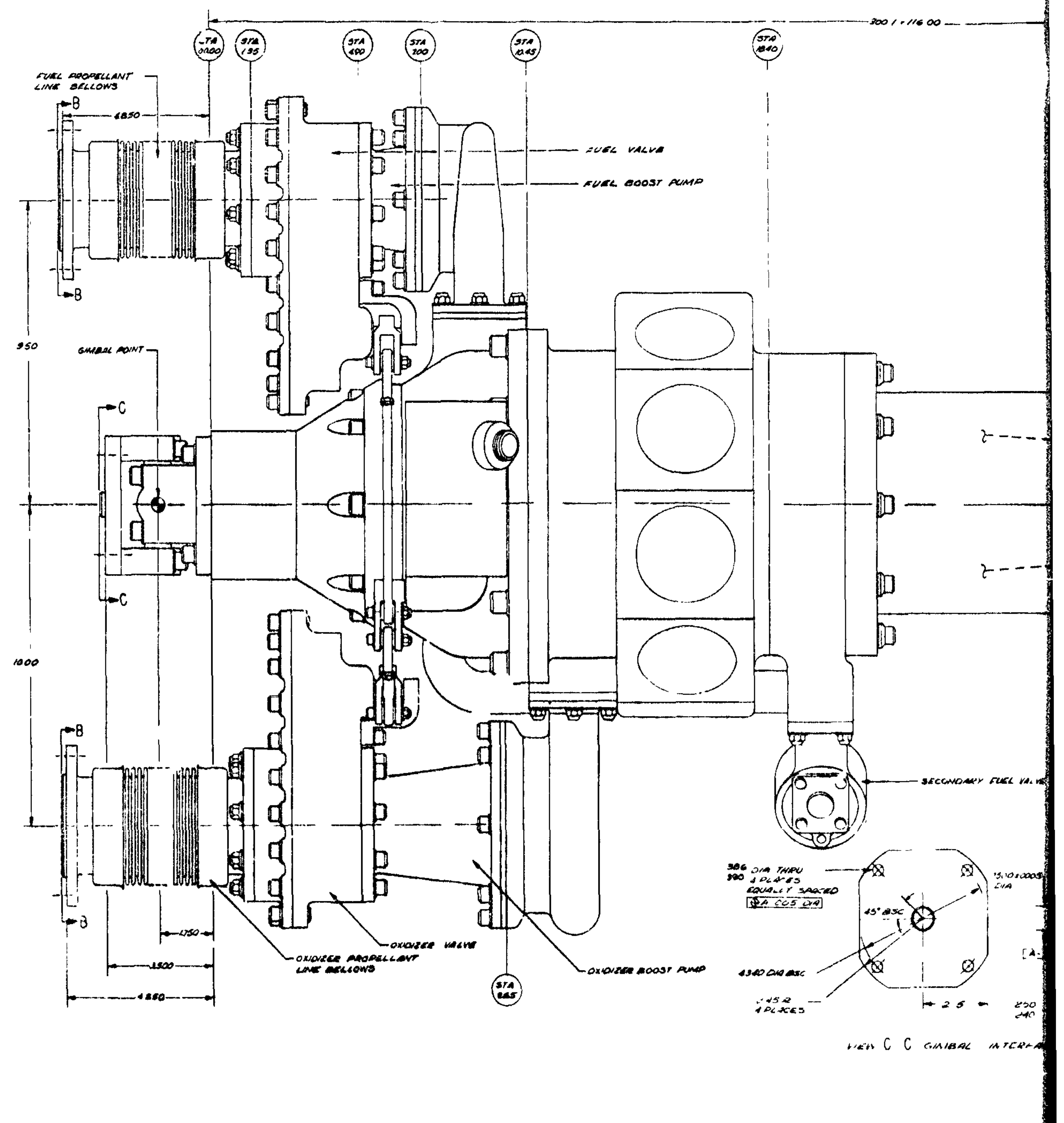


Figure A-2. Cross Section - MIST Engine (U)



FUEL PROPELLANT LINE BELLOWS
FUEL VALVE
FUEL BOOST PUMP
GIMBAL POINT
SECONDARY FUEL VALVE
OXIDIZER PROPELLANT LINE BELLOWS
OXIDIZER VALVE
OXIDIZER BOOST PUMP
STA 0.000
STA 1.35
STA 4.90
STA 7.00
STA 10.45
STA 18.40
STA 8.65
6.850
9.50
10.00
1.750
3.500
4.850
386 DIA THRU
390 4 PLACES
EQUALLY SPACED
45° BSC
4.340 DIA BSC
4 PLACES
VIEW C C GIMBAL INTERFA

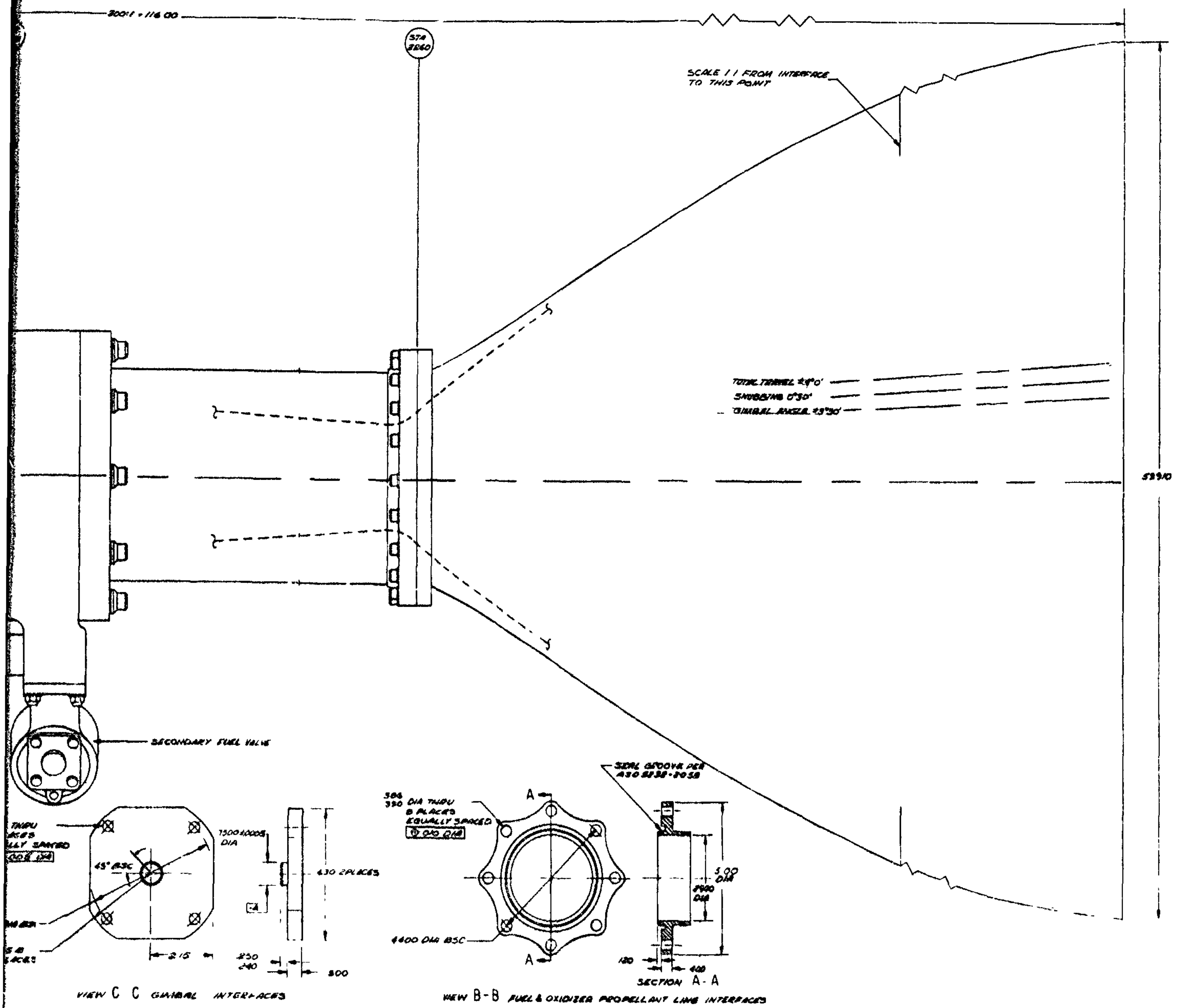
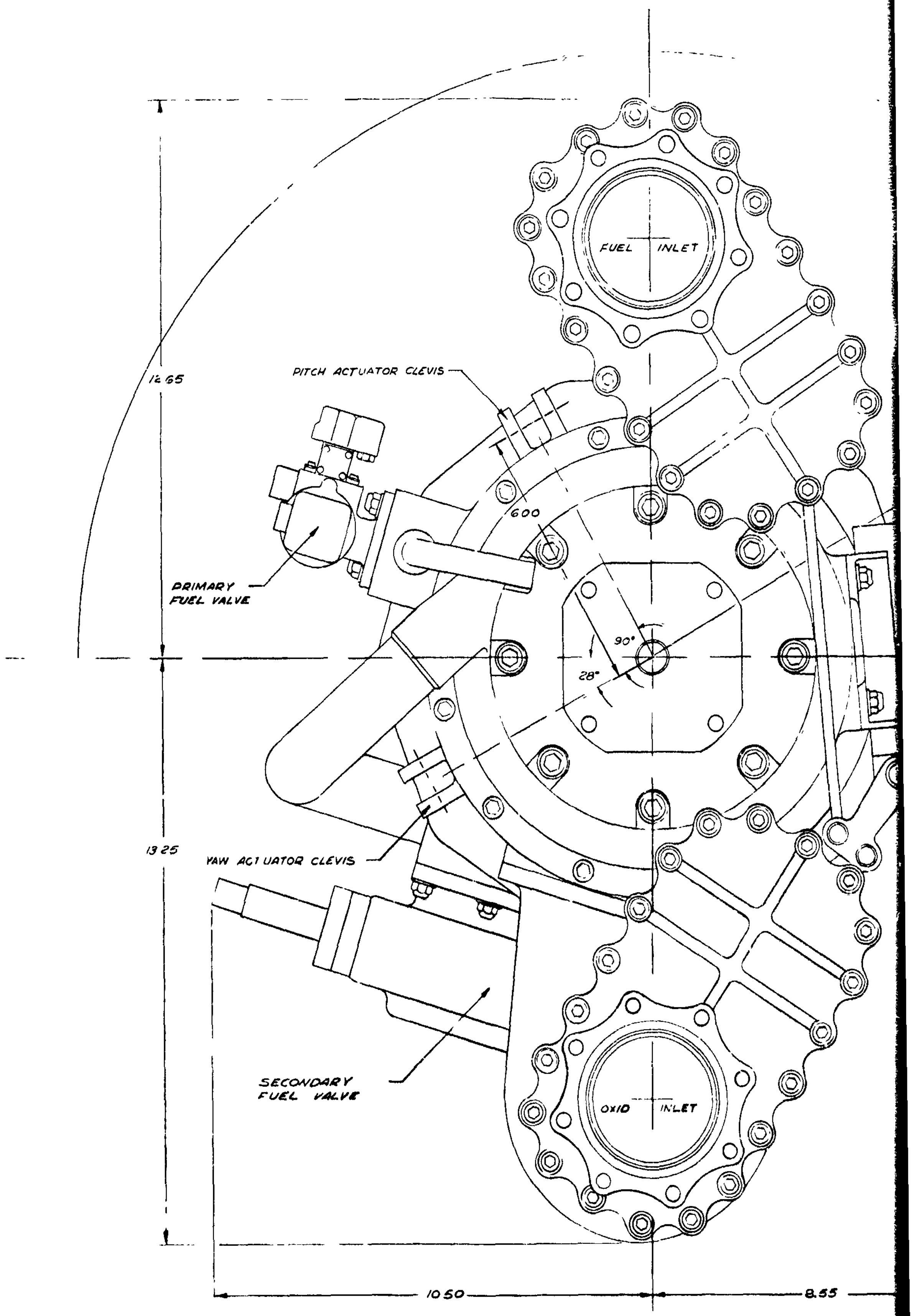


Figure A-3. Cross Section - MIST Engine with Boost Pumps (Sheet 1 of 2)



FUEL INLET
PITCH ACTUATOR CLEVIS
12.65
6.00
PRIMARY FUEL VALVE
90°
28°
13.25
YAW ACTUATOR CLEVIS
SECONDARY FUEL VALVE
OXID INLET
10.50
8.55

F

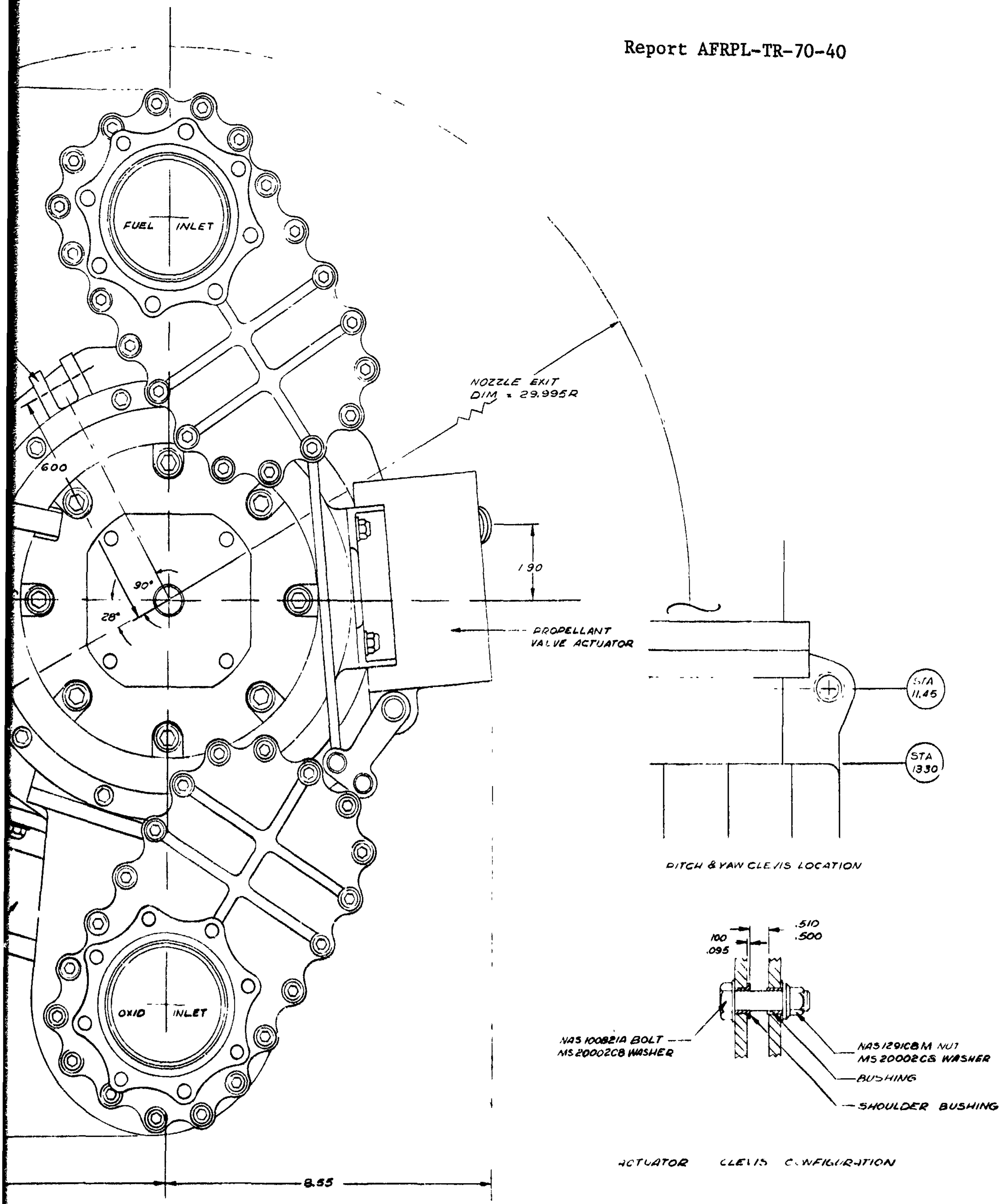


Figure A-3. Cross Section - MIST Engine with Boost Pump (Sheet 2 of 2)

II, Physical Description (cont.)

thrust transmitted through the turbopump to the gimbal which is mounted to the airframe. The turbine exhaust gas discharges directly into the thrust chamber injector.

(C) The primary combustor incorporates a platelet type injector, wherein fuel and oxidizer are introduced between metal plates through photoetched flow passages formed on the surface of each plate. The secondary combustor injector is of the axial platelet type; the fuel is introduced through photoetched platelet pairs and the oxidizer-rich turbine exhaust gas passes over the exterior surface of the platelets.

(U) The secondary combustor (thrust chamber), including the chamber and throat section, together with a portion of the nozzle, is transpiration cooled using platelet washers for metering the required amounts of oxidizer through the thrust chamber wall. The nozzle extension is cooled by a carryover of the transpiration coolant and radiation and is similar in design to the radiation-cooled nozzle of the Apollo engine.

(U) The turbopump shaft is supported in the housing by propellant-lubricated rolling contact bearings. The turbine is on the lower end of the shaft; the single-stage oxidizer pump is on the center of the shaft, with the two-stage fuel pump on the top end of the shaft. Shrouded pump impellers with large running clearances are used to preclude pump rubbing. An interpropellant vented cavity seal is located between the suction sides of the oxidizer pump and first stage fuel pump to separate the propellants.

III. OPERATION

A. STEADY STATE

(C) The engine cycle is shown schematically in Figure A-4. Detailed engine operating parameters over its throttling range are presented in Table A-1. Symbols used in Table A-I are defined in Table A-II. For descriptive purposes operation at the 50,000 lb thrust is used. Except for pressure and speeds, the dynamics of operation are identical at other thrust conditions. Propellants enter the engine through the suction valves. All of the oxidizer (N_2O_4) is ther pumped to a pressure of 5700 psia in the main oxidizer pump with most of it continuing to the primary combustor injector. The fuel is pumped to a pressure of 5100 psia in the first stage fuel pump. A portion of this fuel (20%) then enters the second stage fuel pump where it is pumped to 6800 psia and passes through the primary combustor fuel control valve to the primary injector. The oxidizer and fuel enter the primary combustor where they ignite hypergolically at a mixture ratio of 10.4 to form a hot gas of 1400°F and 5200 psi chamber pressure. This oxidizer-rich gas then passes through the turbine and is then exhausted into the thrust chamber. The major portion of the fuel flow from the first stage pump is ducted through the secondary combustor fuel control valve to the main injector where it is injected into the thrust chamber. Thie fuel burns with the oxidizer-rich turbine exhaust in the thrust chamber at the 2800 psia chamber pressure.

(U) If boost pumps are used, they are driven by hydraulic turbines which use 10% of the respective propellant bled from the main pump discharge. This drive fluid is then exhausted into the boost pump discharge. In the main turbopump, oxidizer for bearing coolant is bled from the pump discharge, passed through the oxidizer bearings, and discharged into the turbine inlet where it provides some turbine cooling. High pressure fuel is used to cool the fuel pump bearings. Secondary combustor transpiration coolant, N_2O_4, is tapped from the oxidizer circuit at the primary injector.

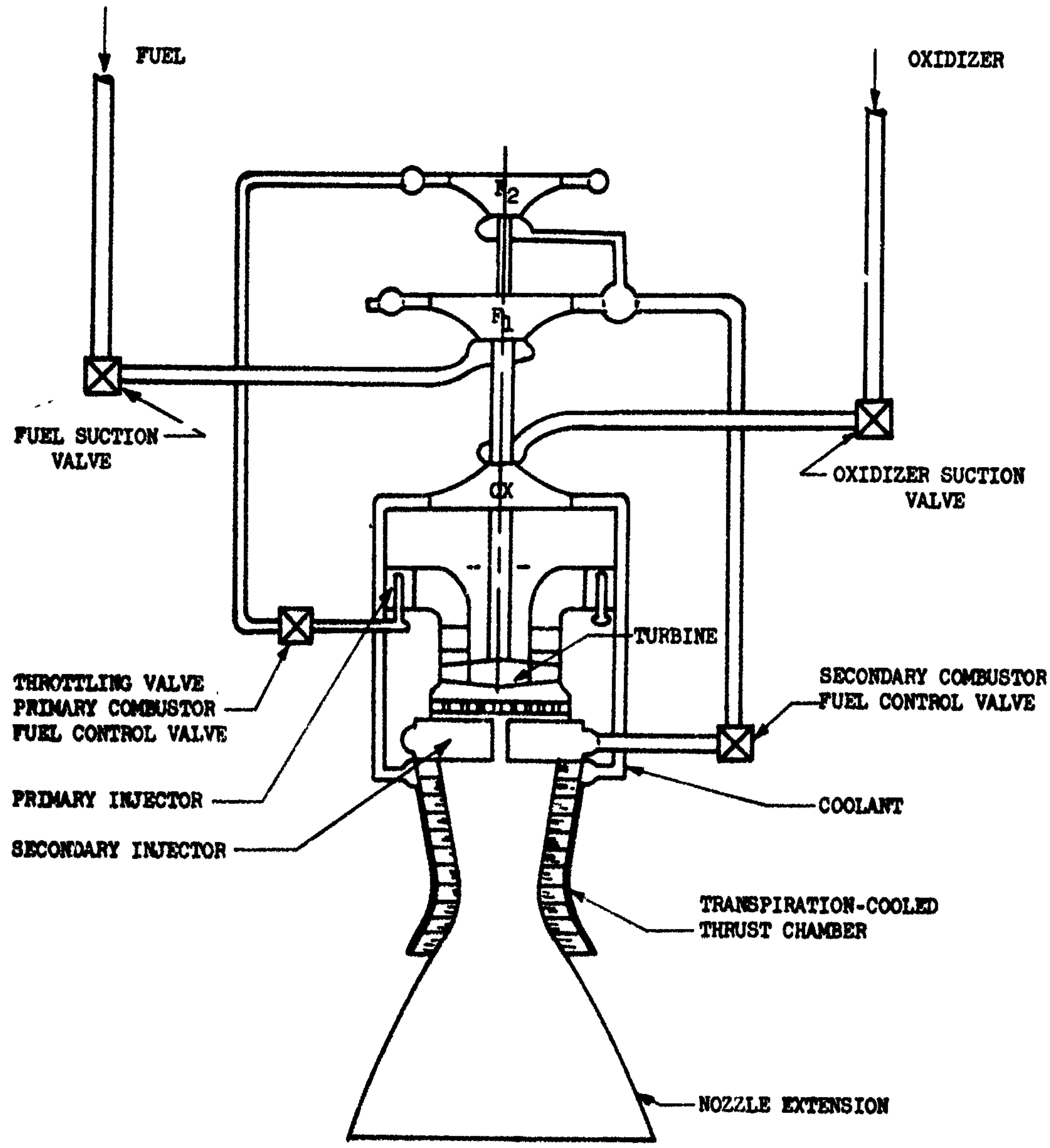


Figure A-4. Engine Schematic (U)

TABLE A-I

ENGINE PARAMETERS, INITIAL (U)

PAGE 1	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
PCSC	2799.99960	2097.65666	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492
MR-ENG	2.41572	2.42792	2.44005	2.43487	2.42444	2.36551	2.37181	2.74724
IS	338.00557	336.03625	333.25032	331.69607	329.43365	325.46622	321.50514	306.40238
W-ENG	147.96269	111.57386	75.00069	60.28098	45.52401	30.72453	23.32918	16.32664
WOT	104.64036	79.02541	53.19829	42.73104	32.22763	21.59539	16.41040	11.97025
WFT	43.31662	32.54859	21.80206	17.54956	13.29406	9.12932	6.91900	4.35715
NT	36999.60107	30176.49805	22867.35547	19749.37646	16441.24097	12886.99866	10891.94800	8622.70764
RPT	1.67215	1.55882	1.42933	1.37759	1.32559	1.27284	1.24376	1.20871
POEIT	51.02575	51.49659	51.83836	51.93886	52.01765	52.07493	52.09465	52.10726
TOEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
PFEIT	21.75524	22.45058	22.95727	23.10511	23.22274	23.30826	23.34149	23.36916
TFEIT	77.00900	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
ATSC	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229	9.30229
ATT	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757	1.64757
ATT*	1.57563	1.53420	1.49902	1.47589	1.44547	1.40098	1.37347	1.33586
ATOBP	.02765	.02765	.02765	.02765	.02765	.02765	.02765	.02765
ATFBP	.01280	.01280	.01280	.01280	.01280	.01280	.01280	.01280
KWFSCV	1.89585	1.89585	1.89525	1.89585	1.89585	1.99585	1.89585	1.89585
KWFPCV	.50030	.25797	.16838	.14555	.12449	.10270	.09163	.08149
CSFOR	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095	6057.04095
CPFOR	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595	28703.09595
CPOOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
COBTOR	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000	200786.50000
CFBTOR	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438	738188.23438
COFCT	192701.97461	193506.48047	194702.60938	195385.59375	196313.13477	197626.90820	198627.05273	200152.40820
DOFCOR	.25583	.25583	.25583	.25583	.25583	.25583	.25583	.25583
KWOBY	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
KWFBY	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
CTIME	4.59170	8.49660	7.82000	6.47700	6.87650	6.61470	7.84380	2.97500

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV. F=37500
CASE 3 THROTTLE W/ FPCV. F=25000
CASE 4 THROTTLE W/ FPCV. F=20000
CASE 5 THROTTLE W/ FPCV. F=15000
CASE 6 THROTTLE W/ FPCV. F=10000
CASE 7 THROTTLE W/ FPCV. F=7500
CASE 8 THROTTLE W/ FPCV. F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 2	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
POT	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000
POSTB	46.16808	48.99314	51.04378	51.64674	52.11952	52.46316	52.58149	52.65716
POSB	40.68841	45.86797	49.62756	50.73302	51.59979	52.22979	52.44673	52.58546
PODR	145.54107	126.41642	102.85377	92.96816	82.89013	73.02516	67.86360	62.38967
POSTM	135.20481	120.40010	100.03030	91.10299	81.79188	72.50135	67.54735	62.21523
POSM	128.51244	116.52212	98.22409	89.91581	81.09789	72.17438	67.35164	62.10801
PODM	5678.55737	3897.67178	2336.65689	1787.00163	1280.33464	826.26543	611.34128	404.47927
POM	5661.65131	3888.47754	2332.95483	1784.87918	1279.41663	826.19556	611.53695	404.81832
POJPC	5646.71991	3879.94571	2329.09018	1782.39340	1278.01111	825.57920	611.18755	404.63346
PFT	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000
PFSTB	14.04590	18.18697	21.20452	22.08497	22.78552	23.29484	23.49273	23.65752
PFSB	5.87490	13.49235	19.04311	20.66270	21.95136	22.88825	23.25226	23.55539
PFDB	83.55895	71.84718	56.60793	50.07616	43.43273	36.82246	33.50067	30.20750
PFSTM1	76.31833	67.69612	54.69453	48.81477	42.69048	36.45864	33.28444	30.11473
PFSM1	67.91231	62.87632	52.47662	47.35470	41.83322	36.03990	33.03630	30.00887
PFDM1	5135.84387	3531.91788	2104.50824	1599.66646	1134.91560	718.23898	522.25422	333.63614
PSCOR	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130
PSCV	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130
PFSCM	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.84207	482.05486	317.97361
PFJSC	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.84207	482.05486	317.97361
PFSTM2	5070.03558	3494.04678	2087.07230	1588.20117	1128.20099	714.97482	520.32830	332.82227
PFSM2	5069.62292	3493.84415	2086.99005	1588.14909	1128.17099	714.96002	520.31908	332.81747
PFDM2	6783.81042	4723.39929	2827.90866	2148.69815	1521.22769	958.74412	695.18646	442.83855
PFPOR	6690.97443	4679.62054	2809.30145	2136.93512	1514.62633	955.66185	693.35930	442.07576
PFPCV	6259.57428	4475.92688	2730.46854	2088.16199	1487.28947	942.60142	685.38762	438.02097
PFPCM	5915.58417	3936.31119	2325.60370	1789.63341	1292.15045	834.52796	616.29827	404.77417
PFJPC	5909.50714	3933.79346	2324.80148	1789.19174	1291.93935	834.44840	616.25780	404.75877
PCPC	5190.95874	3597.55630	2186.55225	1685.20627	1218.83098	788.56866	583.22816	384.12576
PTIT	5049.89966	3499.79633	2127.13489	1639.41248	1185.71046	767.23738	567.37952	373.68752
PTFT	3031.84540	2252.36816	1492.05974	1192.89618	896.39140	603.87495	456.91117	309.59784
PTE	3020.00000	2245.15240	1488.20470	1190.05440	894.47815	602.77700	456.18209	309.16123
PPI	3020.14005	2245.10995	1498.12440	1190.03214	894.45525	602.71902	456.09389	309.09309
PPE	2931.84650	2190.83707	1459.00121	1168.93823	880.25053	594.27000	450.13311	305.42107
PCFACE	2890.00000	2165.08371	1445.16150	1158.91188	873.49461	590.24858	447.29484	303.67188
PCSC	2799.99960	2097.65866	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492
PESC	.42596	.32010	.21433	.17155	.12880	.08470	.06424	.04020

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV. F=37500
CASE 3 THROTTLE W/ FPCV. F=25000
CASE 4 THROTTLE W/ FPCV. F=20000
CASE 5 THROTTLE W/ FPCV. F=15000
CASE 6 THROTTLE W/ FPCV. F=10000
CASE 7 THROTTLE W/ FPCV. F=7500
CASE 8 THROTTLE W/ FPCV. F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 3	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
DP/PSF	.07976	.06520	.04767	.04002	.03181	.02341	.01833	.01112
DP/PPC	.09343	.08314	.06865	.06056	.05081	.04833	.04911	.05433
DP/PPF	.13844	.09347	.06323	.06171	.05998	.05805	.05663	.05371
PCSC	2799.99960	2097.65866	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492
MRSC	2.20000	2.20888	2.21865	2.21258	2.20118	2.13944	2.14111	2.49228
AE/AT	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794	299.99794
ETAC	.99188	.98967	.98756	.98666	.98573	.98424	.98341	.98316
ETAN	.92697	.92396	.91861	.91487	.90899	.89791	.88754	.86847
C*SC	5663.70313	5626.87305	5587.35156	5574.74481	5563.83972	5570.63324	5559.67273	5393.40002
CF	1.92012	1.92143	1.91898	1.91435	1.90502	1.87978	1.86056	1.82782
WGJSC	104.04743	77.55334	51.57234	41.20716	30.90544	20.54246	15.53569	11.30450
WFJSC	34.56004	26.89136	18.60042	15.17180	11.64895	8.11872	6.19790	3.91216
WDFC	9.35002	7.12936	4.82747	3.90144	2.97028	2.06366	1.59597	1.11062
WFC/WT	.06319	.06390	.06437	.06472	.06525	.06717	.06841	.06802
DPFJSC	168.06671	103.53839	50.94221	34.45125	20.76068	10.40594	6.21493	2.58714
DPOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
WOJPC	91.13517	68.62238	46.02486	36.86686	27.69097	18.31919	13.78734	10.02634
WFJPC	8.75658	5.65724	3.20164	2.37775	1.64512	1.01061	.72110	.44499
MRPC	10.40762	12.13002	14.37540	15.50491	16.83223	18.12694	19.11988	22.53152
TTIT	1400.10164	1219.46159	1175.66423	1165.96980	1164.45190	1187.39537	1205.10089	1181.92430
KGTI	1.25221	1.24711	1.24098	1.23996	1.24149	1.24654	1.25272	1.25858
RGTI	47.59236	45.01923	42.25354	41.08126	39.87002	38.85803	38.16378	33.04282
	236.29641	227.19951	217.59354	212.27901	204.96897	196.46922	189.17519	160.82987
C*PC	2562.78549	2325.73523	2084.05545	1983.66655	1879.70274	1789.12054	1728.12715	1533.81288
HOB	164.79651	127.36484	84.62177	67.29646	49.96876	33.28850	24.70594	15.72145
HFB	201.00394	150.70547	96.84434	75.77663	55.30142	35.84579	26.35259	17.09461
HOM	8978.73022	6110.26855	3613.36777	2738.28061	1934.09029	1215.56755	876.64743	551.55984
HFM1	13226.17834	9027.58044	5323.09955	4020.35272	2826.96634	1761.13057	1262.08604	782.09409
HFM2	4905.43347	3405.86746	2004.40904	1504.23953	1046.87180	644.63547	460.66193	288.59128
NPSHOE	45.92397	50.47866	53.78460	54.75663	55.51878	56.07274	56.26349	56.38548
NPSHFE	29.08461	39.71678	47.46400	49.72441	51.52294	52.83051	53.33854	53.76159
NPSHOM	186.86927	163.58992	131.30132	117.11488	102.30433	87.50762	79.63420	71.23844
NPSHFM	188.25339	166.21330	132.93567	117.89203	102.22940	86.30369	78.19633	70.09695
NPSPOB	28.54422	31.37634	33.43210	34.03657	34.51053	34.85502	34.97365	35.04951
NPSPFB	11.33037	15.47269	18.49116	19.37188	20.07264	20.58211	20.78006	20.94490
NPSPOM	115.84853	101.48799	81.50263	72.71025	63.52596	54.34547	49.46045	44.25490
NPSPFM	72.99051	64.51433	51.65218	45.82580	39.75379	33.57486	30.42736	27.28084

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 8 THROTTLE W/ FPCV, F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 4	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
ETA-T	.72417	.70721	.65587	.62273	.57649	.50854	.46192	.40911
WTI	99.89175	74.27962	49.22650	39.24461	29.33609	19.32980	14.50844	10.47133
U/C-GT	.48399	.45312	.38519	.35100	.30996	.25847	.22723	.19475
SHPT	5685.54987	2988.63614	1250.23013	789.37869	445.18677	207.92389	122.49430	57.96613
SHPOM	3095.91287	1633.72458	686.19165	434.16777	245.35813	114.67516	67.92716	33.44826
SHPFM1	2287.13950	1199.00391	457.19525	312.91241	175.63265	81.59637	47.55383	21.01070
SHPFM2	300.84079	158.01094	66.86947	42.65581	24.42165	11.71639	7.07982	3.52670
RPT	1.67215	1.55882	1.42933	1.37759	1.32559	1.27284	1.24376	1.20871
POSTM	135.20481	120.40010	100.03030	91.10299	81.79188	72.50135	67.54735	62.21523
PODTM	5701.51709	3911.09134	2342.95496	1791.15221	1282.76683	827.41385	612.02927	404.85644
HOMNC	8979.33948	6109.60181	3613.36871	2738.28226	1934.09071	1215.56902	876.64919	551.56396
QOSM	580.61271	441.82129	301.44349	244.36477	186.81782	128.22523	99.19727	73.41606
HOM/N2	-5 65591913	-5 67092692	-5 69100372	-5 70205547	-5 71549671	-5 73194095	-5 73894940	-5 74183711
Q/QDUM	.99988	.93290	.83994	.78840	.72401	.63399	.58030	.54251
ETA-OM	.60899	.59804	.57481	.55820	.53346	.49243	.46386	.43874
NSO	966.51167	917.87294	851.89246	815.57533	770.52401	708.84920	673.34261	649.14590
SOM	17640.02100	13867.14148	10235.97607	8672.13123	6986.11047	5100.54175	4069.51727	3013.11398
D*OSM	89.27197	89.33479	89.38507	89.40175	89.41692	89.42933	89.43778	89.45599
PFSTM1	76.31833	67.69612	54.69453	48.81477	42.69048	36.45864	33.28444	30.11473
PFDTM1	5204.85425	3571.55325	2122.77673	1611.69969	1141.98445	721.69334	524.30166	334.50968
HFMNC1	13226.32520	9027.58484	5323.09961	4020.35275	2826.96637	1761.13058	1262.08606	782.09409
QFSM1	406.64429	310.04911	212.47947	173.44744	134.03779	94.86620	73.82770	49.41988
HF1/N2	-5 96615121	-5 99136570	-4 10179646	-4 10307596	-4 10458068	-4 10604446	-4 10638437	-4 10518933
Q/QDF1	1.09549	1.02412	.92617	.87539	.81261	.73375	.67562	.57128
ETAFM1	.53190	.52859	.51564	.50534	.48943	.46469	.44478	.41766
NSF-1	604.95779	573.72725	534.87350	515.15665	490.97324	461.70433	441.97585	409.87395
SFM1	14681.13000	11478.81213	8514.42834	7270.03015	5920.77527	4432.99982	3559.07886	2502.25952
D*FM1	55.83237	55.89242	55.95123	55.97423	55.99706	56.02055	56.03254	56.04297
PFSTM2	5070.03558	3494.34678	2087.07230	1588.20117	1128.20099	714.97482	520.32830	332.82227
PFDTM2	6980.67706	4820.06427	2867.11868	2173.52573	1535.52271	965.79538	699.57442	445.12442
HFMNC2	4905.43347	3405.86746	2004.40904	1504.23953	1046.87180	644.63547	460.66193	288.59128
QFSM2	96.95612	67.95642	43.29627	34.45867	26.15241	18.37136	14.49793	10.46224
HF2/N2	-5 35833011	-5 37401589	-5 38331380	-5 38566499	-5 38727931	-5 38815986	-5 38830340	-5 38814668
Q/QDF2	1.08706	.93420	.78544	.72381	.65986	.59138	.55202	.50334
ETAFM2	.35922	.33269	.29464	.27584	.25446	.22943	.21407	.19435
NSF-2	621.55087	557.97322	502.28653	479.97099	456.84664	431.75451	417.02493	398.33066
NT	36999.60107	30176.49805	22867.35547	19749.37646	16441.24097	12886.99866	10891.94800	8622.70764

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 8 THROTTLE W/ FPCV, F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 5	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
NTOB	12060.08008	9910.92163	7553.14008	6538.32922	5456.39355	4288.56812	3624.14212	2856.83514
WOSB	104.64036	79.02541	53.19829	42.73104	32.22763	21.59539	16.41040	11.97025
TOSB	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
POSTB	46.16808	48.95314	51.04378	51.64674	52.11952	52.46316	52.58149	52.65716
PODTB	148.59799	128.16010	103.64404	93.47804	83.18015	73.15541	67.93881	62.42969
HOBNC	165.69230	127.60785	84.66467	67.31367	49.97422	33.28965	24.70633	15.72154
QOSB	524.69964	396.24397	266.73639	214.25191	161.58719	108.27737	82.28020	60.01763
HOB/N2	-5 11392031	-5 12991201	-5 14840453	-5 15745981	-5 16785512	-5 1810025[illegible]	-5 18810388	-5 19263030
Q/QDOB	1.16201	1.06782	.94320	.87520	.79095	.67433	.60637	.56110
ETAOB	.59786	.61975	.60909	.59012	.55738	.50034	.46133	.42986
SHPOB	52.44305	29.52839	13.43804	8.86001	5.25304	2.61231	1.59790	.79600
SOB	15659.87219	10417.81677	6211.37030	4754.59808	3410.29102	2177.85803	1600.27667	1075.62622
PTITOB	3908.83594	2689.93500	1620.16797	1243.21922	895.61680	584.00416	436.44977	294.35674
DPTOB	3763.29486	2563.51855	1517.31419	1150.25105	812.72667	510.97899	368.58617	231.96706
TTITOB	101.10693	94.32657	88.45785	86.37250	84.42132	82.64503	81.64768	80.28546
WTOB	10.85083	8.92025	6.83858	5.94685	4.99313	3.95519	3.35783	2.66323
ETATOB	.44923	.44811	.44626	.44522	.44395	.44241	.44154	.44046
NTFB	14180.32434	11636.53992	8838.54150	7638.40338	6360.75812	4980.03906	4194.20209	3284.49274
WFSB	43.31662	32.54859	21.80206	17.54956	13.29406	9.12932	6.91900	4.35715
TFSB	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
PFSTB	14.04590	18.16657	21.20452	22.08491	22.78552	23.29484	23.49273	23.65752
PFDTB	92.35020	76.89815	58.93340	51.60640	44.33021	37.25992	33.75939	30.31738
HFBNC	201.49904	150.73983	96.84611	75.77705	55.30149	35.84580	26.35260	17.09461
QFSB	346.54838	260.39383	174.41670	140.39590	106.35164	73.03378	55.35132	34.85674
HFB/N2	-5 10020769	-5 11132182	-5 12397125	-5 12987708	-5 13668444	-5 14453490	-5 14980444	-5 15846111
Q/QDFB	1.08444	.99297	.87566	.81561	.74193	.65076	.58561	.47092
ETAFB	.62796	.62833	.59956	.57620	.54177	.49196	.45300	.38011
SHPFB	25.20966	14.19410	6.40287	4.19628	2.46728	1.20943	.73182	.35628
SFB	21078.16821	11869.18555	6455.25775	4833.53424	3411.08624	2171.91721	1581.04678	976.71943
PTITFB	3807.28156	2616.50314	1558.93089	1185.54143	842.19587	534.79593	390.36483	251.46733
DPTFB	3723.72260	2544.65594	1502.32295	1135.46526	798.76314	497.97346	356.86416	221.25983
TTITFB	107.14187	98.59249	91.06706	88.34954	85.78525	83.33206	82.11070	80.85474
WTFB	3.91124	3.23228	2.48286	2.15835	1.81017	1.42926	1.20994	.95276
ETATFB	.37096	.36963	.36755	.36648	.36518	.36365	.36272	.36173
WOTS	2.04618	1.62318	1.17309	.98281	.78540	.61796	.53214	.44455
WOBY	1.07141	.83184	.58537	.48698	.38782	.29339	.24413	.19192
WFBY	1.03608	.81870	.59738	.49276	.39613	.30131	.25098	.19670
WFPTS	3.36019	2.83186	2.20459	1.92442	1.61975	1.28290	1.08842	.86130

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 8 THROTTLE W/ FPCV, F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 6	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
POT	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000
DPOEI	16.44482	9.11209	3.78942	2.22437	.99723	.10529	-.20186	-.39827
POEIT	51.02575	51.49659	51.83836	51.93886	52.01765	52.07493	52.09465	52.10726
POEI	35.05518	42.38791	47.71058	49.27563	50.50277	51.39471	51.70186	51.89827
DPOSB	-5.63323	-3.48006	-1.91701	-1.45740	-1.09702	-.83507	-.74487	-.68719
POSTB	46.16808	48.99314	51.04378	51.64674	52.11952	52.46316	52.58149	52.65716
POSB	40.68841	45.6679.	49.62758	50.73302	51.59979	52.22979	52.44673	52.58546
PODTB	148.59799	128.16010	103.64404	93.47804	83.18015	73.15541	67.93881	62.42969
PODB	145.54107	126.41642	102.85377	92.96816	82.89013	73.02516	67.86360	62.38967
DPOSM	17.02863	9.89430	4.62969	3.05235	1.79223	.85079	.51196	.28166
POSTM	135.20481	120.49010	100.03030	91.10299	81.79188	72.50135	67.54735	62.21523
POSM	128.51244	116.52212	98.22409	89.91581	81.09789	72.17438	67.35164	62.10801
PODTM	5701.51709	3911.09134	2342.95496	1791.15221	1282.76683	827.41385	612.02927	404.85644
PODM	5678.55737	3897.67178	2336.65689	1787.00163	1280.33464	826.26543	611.34128	404.47927
DPOH	20.46783	11.45361	4.98917	3.12178	1.68965	.67709	.35264	.16851
POHT	5675.95276	3896.64938	2336.65646	1787.26007	1280.76285	826.78592	611.87162	404.99538
POH	5661.65131	3888.47754	2332.95483	1784.87918	1279.41663	826.19556	611.53695	404.81832
DPOORF	14.93140	8.53183	3.86465	2.48578	1.40552	.61636	.34940	.18486
POJPCT	5675.95276	3896.64938	2336.65646	1787.26007	1280.76285	826.78592	611.87162	404.99538
POJPC	5646.71991	3879.94571	2329.09018	1782.39340	1278.01111	825.57920	611.18755	404.63346
DPOJPC	455.76117	282.38940	142.53793	97.18713	59.18013	36.91054	27.95939	20.50770
PCPC	5190.95874	3597.55630	2186.55225	1685.20627	1218.83098	788.66866	583.22816	384.12576
TOT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
D*OT	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039
WOT	104.64036	79.02541	53.19829	42.73104	32.22763	21.59539	16.41040	11.97025
WOSM	115.49118	87.94566	60.03687	48.67789	37.22075	25.55057	19.76823	14.63348
TODM	101.10693	94.32697	88.45785	86.37250	84.42132	82.64503	81.64768	80.28546
D*ODM	91.57873	90.85628	90.21813	89.99514	89.79204	89.61235	89.53961	89.50108
WOPC	91.13517	68.62238	46.02486	36.86686	27.69097	18.31919	13.78734	10.02634
WOFC	9.35002	7.12936	4.82747	3.90144	2.97028	2.06366	1.59597	1.11062
WTOB	10.85083	8.92025	6.83858	5.94685	4.99313	3.95519	3.35783	2.66323
WOTS	2.10749	1.65054	1.17275	.97974	.78395	.59470	.49512	.38863
TOJPC	103.95350	96.08595	89.34118	86.97283	84.78528	82.86700	81.81347	80.40558
D*OJPC	90.99988	90.49996	90.03992	89.87428	89.71896	89.56796	89.50655	89.47722
REOJPC	6719.86176	4799.82550	3078.22818	2427.50638	1797.29466	1174.17178	877.64201	632.40393
REFJSC	36213.98340	25719.69946	16361.19995	12948.75916	9667.19812	6565.67834	4950.01215	3085.40170

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV. F=37500
CASE 3 THROTTLE W/ FPCV. F=25000
CASE 4 THROTTLE W/ FPCV. F=20000
CASE 5 THROTTLE W/ FPCV. F=15000
CASE 6 THROTTLE W/ FPCV. F=10000
CASE 7 THROTTLE W/ FPCV. F=7500
CASE 8 THROTTLE W/ FPCV. F=5000

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TABLE A-I (cont.)

PAGE 7	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14025	9999.79663	7500.45233	5002.52124
PFT	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000	23.00000
DPFEI	9.41650	5.24446	2.20433	1.31729	.61150	.09837	-.10100	-.26702
PFEIT	21.75524	22.45058	22.95727	23.10511	23.22274	23.30826	23.34149	23.36916
PFEI	13.58350	17.75554	20.79567	21.68271	22.38850	22.90163	23.10100	23.26702
DPFSB	7.70860	4.26319	1.75256	1.02001	.43714	.01338	-.15126	-.28837
PFSTB	14.04590	18.18697	21.20452	22.08497	22.78552	23.29484	23.49273	23.65752
PFSB	5.87490	13.49235	19.04311	20.66270	21.95136	22.88825	23.25226	23.55539
PFDTB	92.35020	76.89815	58.93340	51.60640	44.33021	37.25992	33.75939	30.31738
PFDB	83.55895	71.64718	56.60793	50.07616	43.43273	36.82246	33.50067	30.20750
DPFSM	21.00696	21.00696	21.00696	21.00696	21.00696	21.00696	21.00696	21.00696
PFSTM	76.31833	67.69612	54.69453	48.81477	42.69048	36.45864	33.28444	30.11473
PFSM	67.91231	62.87632	52.47662	47.35470	41.83322	36.03990	33.03630	30.00887
PFDTM1	5204.85425	3571.55325	2122.77673	1611.69969	1141.98445	721.69334	524.30166	334.50968
PFDM1	5135.84387	3531.91788	2104.50824	1599.66646	1134.91560	718.23898	522.25422	333.63614
DPSCL	900.26923	544.02621	259.79826	172.68219	101.64490	49.20655	28.55066	11.19745
PSCORT	4304.92139	3027.64993	1863.00653	1439.02991	1040.34386	672.48781	495.75135	323.31229
PSCOR	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130
DPSCOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
PSCVT	4304.92139	3027.64993	1863.00653	1439.02991	1040.34386	672.48781	495.75135	323.31229
PSCV	4242.94507	2990.18460	1845.10246	1427.12230	1033.32628	669.08014	493.76570	322.52130
DPSCV	372.34891	224.77548	107.22556	71.23007	41.88982	20.23807	11.71083	4.54769
PFSCMT	3932.71283	2802.92551	1755.79259	1367.80496	998.45582	652.25015	484.04065	318.76461
PFSCM	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.84207	482.05486	317.97361
DPFSCM	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
PFJSCT	3932.71283	2802.92551	1755.79259	1367.80496	998.45582	652.25015	484.04065	318.76461
PFJSC	3870.59616	2765.40912	1737.87691	1355.89223	991.43646	648.84207	482.05486	317.97361
DPFJSC	980.59616	600.32541	292.71541	196.98035	117.94196	58.59349	34.76003	14.30173
PCFACE	2890.00000	2165.08371	1445.16150	1158.91188	873.49461	590.24858	447.29484	303.67188
TFT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
DWFT	56.10064	56.10064	56.10054	56.10064	56.10064	56.10064	56.10064	56.10064
WFT	43.31662	32.54859	21.80206	17.54956	13.29406	9.12932	6.91900	4.35715
WFSM1	50.58805	38.61274	26.48950	21.63232	16.72398	11.84148	9.21736	6.17121
TFDM1	107.14187	98.59249	91.06796	88.34954	85.78525	83.33206	82.11070	80.85474
DWFDM1	56.11254	56.07852	56.04649	56.03719	56.03077	56.03007	56.03195	56.03635
WFSM2	12.11677	8.48910	5.40623	4.30217	3.26487	2.29351	1.80952	1.30629
WFJSC	34.56004	26.89136	18.60042	15.17180	11.64895	8.11872	6.19790	3.91216
TFJSC	118.16530	105.27084	94.27831	90.49453	87.05733	83.95567	82.47691	81.00273
DWFJSC	55.32790	55.60240	55.81730	55.88407	55.93997	55.98559	56.00586	56.02586

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV. F=37500
CASE 3 THROTTLE W/ FPCV. F=25000
CASE 4 THROTTLE W/ FPCV. F=20000
CASE 5 THROTTLE W/ FPCV. F=15000
CASE 6 THROTTLE W/ FPCV. F=10000
CASE 7 THROTTLE W/ FPCV. F=7500
CASE 8 THROTTLE W/ FPCV. F=5000

JOB 16145 REVISED 24 MAR. 69 DATE OF THIS RUN 02 APR. 1969 00000000

TABLE A-I (cont.)

PAGE 8	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
PFDTM1	5204.85425	3571.55325	2122.77673	1611.69969	1141.98445	721.69334	524.30166	334.50968
PFDM1	5135.84387	3531.91788	2104.50824	1599.66646	1134.91560	718.23898	522.25422	333.63614
DPFSM2	66.22095	38.07373	17.51819	11.51736	6.74461	3.27896	1.93513	.81868
PFSTM2	5070.03558	3494.04678	2087.07230	1588.20117	1128.20099	714.97482	520.32830	332.82227
PFSM2	5069.62292	3493.84415	2086.99005	1588.14909	1128.17099	714.96002	520.31908	332.81747
PFDTM2	6980.67706	4820.06427	2867.11868	2173.52573	1535.52271	965.79538	699.57442	445.12442
PFDM2	6783.81042	4723.39929	2827.90066	2148.69815	1521.22769	958.74412	695.18646	442.83855
DPFPCL	92.10547	45.03687	18.08578	11.34351	6.40701	3.01244	1.76441	.77939
PFPCRT	6887.95074	4776.31189	2848.51581	2161.76443	1528.92191	962.71325	697.74731	444.36164
PFPCR	6690.97443	4679.62054	2809.30145	2136.93512	1514.62633	955.66185	693.35930	442.07576
DPFPOF	431.40015	203.69366	78.83292	48.77313	27.33685	13.06043	7.97168	4.05479
PFPCVT	6362.77753	4518.93500	2744.23035	2095.74945	1490.91995	943.97769	686.08451	438.28625
PFPCV	6259.57428	4475.92688	2730.46854	2088.16199	1487.28947	942.60142	685.38762	438.02097
DPFPCV	343.99011	539.61569	404.86484	298.52858	195.13902	108.07346	69.08935	33.24680
PFPCMT	6019.00366	3979.46060	2339.39935	1797.23460	1295.78522	835.89812	616.99545	405.03950
PFPCM	5915.58417	3936.31119	2325.60370	1789.63341	1292.15045	834.52796	616.29827	404.77417
DPFPCM	6.07703	2.51773	.80222	.44167	.21111	.07956	.04047	.01540
PFJPCT	5909.57422	3933.82144	2324.81046	1789.19667	1291.94171	834.44930	616.25826	404.75894
PFJPC	5909.50714	3933.79346	2324.80148	1789.19174	1291.93935	834.44840	616.25780	404.75877
DPFJPC	718.54840	336.23715	138.24924	103.98547	73.10837	45.77974	33.02964	20.63301
PCPC	5190.95074	3597.55630	2186.55225	1685.20627	1218.83098	788.66866	583.22816	384.12576
TFSM2	107.14157	98.59249	91.06706	88.34954	85.78525	83.33206	82.11070	80.85474
D*FSM2	56.08727	56.06399	56.03980	56.03279	56.02819	56.02881	56.03120	56.03603
WFSM2	12.11677	8.48910	5.40623	4.30217	3.26487	2.29351	1.80952	1.30629
TFDM2	123.25920	111.14205	99.88475	95.59744	91.41651	87.30797	85.20890	83.05076
D*FDM2	55.93229	55.91336	55.90528	55.91175	55.92528	55.94928	55.96619	55.98720
WFJPC	8.75658	5.65724	3.20164	2.37775	1.64512	1.01061	.72110	.44499
WFRTS	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
TFJPC	131.78693	116.96545	103.11553	97.91363	92.91802	88.14769	85.76055	83.34069
D*FJPC	55.32563	55.49869	55.67501	55.74660	55.81818	55.88937	55.92684	55.96653
REFJPC	5003.36780	2933.60431	1503.63565	1073.52443	714.28022	422.22259	295.39222	178.62657

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 8 THROTTLE W/ FPCV, F=5000

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TABLE A-I (cont.)

PAGE 9	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.90391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
PCPC	5190.95874	3597.55630	2196.55225	1685.20627	1218.83098	785.66866	583.22816	384.12576
DPPC	141.05908	97.75998	59.41736	45.79379	33.12051	21.43128	15.84864	10.43823
PTIT	5049.89966	3499.79633	2127.13489	1639.41248	1185.71046	767.23738	567.37952	373.68752
PTET	3031.84540	2252.36816	1492.05974	1192.89618	896.39140	603.87495	456.91117	309.59784
PTE	3020.00000	2245.15240	1488.20470	1190.05440	894.47815	602.77700	456.18209	309.16123
DPTX	-.14005	.05145	.08029	.02226	.02290	.05798	.08820	.06814
PPIT	3031.84540	2252.36816	1492.05974	1192.89618	896.39140	603.87495	456.91117	309.59784
PPI	3020.14005	2245.10095	1488.12440	1190.03214	894.45525	602.71902	456.09389	309.09309
DPPI	88.29355	54.26389	29.12320	21.09390	14.20472	8.44901	5.96078	3.67202
PPET	2943.90494	2198.28418	1463.01497	1171.85406	882.21795	595.44241	450.96120	305.93191
PPE	2931.84650	2190.83707	1459.00121	1168.93823	880.25053	594.27000	450.13311	305.42107
DPJHG	41.84650	25.75336	13.83971	10.02635	6.75593	4.02142	2.83827	1.74920
PCFACE	2890.00000	2165.08371	1445.16150	1158.91188	873.49461	590.24858	447.29484	303.67188
PCSC	2799.99960	2097.65866	1400.15628	1122.82104	846.29224	571.86706	433.36518	294.21492
PESC	.42596	.32010	.21433	.17155	.12880	.08470	.06424	.04020
TGPC	1400.10164	1154.81873	916.72253	822.14769	727.31473	646.87016	595.19215	503.27549
WPC	99.89175	74.27962	49.22650	39.24461	29.33609	19.32980	14.50844	10.47133
TTIT	1400.10164	1219.46159	1175.66473	1165.96950	1164.45190	1187.39537	1205.10089	1181.92430
TTET	1267.62222	1057.41878	852.52657	770.03288	686.59409	616.75777	570.64542	484.34471
TJHGT	1280.13786	1069.71042	864.92714	782.10553	697.67340	626.62718	578.76796	487.72290
WJHG	104.04743	77.55334	51.57234	41.20716	30.90544	20.54246	15.53569	11.30450
PODTM	5701.51709	3911.09134	2342.95496	1791.15221	1282.76683	827.41385	612.02927	404.85644
POFCI	5658.08954	3886.21817	2331.66772	1783.87985	1278.64499	825.58634	610.98864	404.31076
DPOFCL	1277.75122	751.88919	349.31291	229.52733	133.68604	65.21451	39.23078	19.15996
POJFCT	4380.33832	3134.32898	1982.35481	1554.35252	1144.95895	760.37383	571.75786	385.15081
POJFC	4380.33832	3134.32898	1982.35481	1554.35252	1144.95895	760.37383	571.75786	385.15081
DPOJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
POFCD	4380.33832	3134.32898	1982.35481	1554.35252	1144.95895	760.37383	571.75786	385.15081
WOFC	9.35002	7.12936	4.82747	3.90144	2.97028	2.06366	1.59597	1.11062
TOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
D*OJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 5 THROTTLE W/ FPCV, F=5000

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TABLE A-I (cont.)

PAGE 10	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	50012.21436	37492.86035	24994.00391	19994.96362	14997.14026	9999.79663	7500.45233	5002.52124
WFC/WT	.06319	.06390	.06437	.06472	.06525	.06717	.06841	.06802
WOFC	9.35002	7.12936	4.82747	3.90144	2.97028	2.06366	1.59597	1.11062
POFCI	5658.08954	3886.21817	2331.66772	1783.87985	1278.64499	825.58834	610.98864	404.31076
POFCDO	4380.33832	3134.32898	1982.35481	1554.35252	1144.95895	760.37383	571.75786	385.15081
D*OFC	91.19613	90.63428	93.11629	89.92861	89.75352	89.59380	89.52852	89.49563
WOFC1	1.41029	1.0520	.68956	.54712	.40708	.27562	.20988	.14336
WOFC2	2.09126	1.56965	1.03674	.82633	.61822	.42100	.32161	.22049
WOFC3	1.99226	1.51191	1.01572	.81704	.61815	.42605	.32774	.22648
WOFC4	.94191	.72154	.49178	.39870	.30456	.21215	.16422	.11432
WOFC5	.93313	.72049	.49706	.40564	.31241	.21961	.17093	.11977
WOFC6	.74160	.57751	.40366	.33177	.25779	.18307	.14339	.10125
WOFC7	.54046	.40065	.28341	.23448	.18369	.13172	.10379	.07385
WOFC8	.26708	.21150	.15164	.12638	.09993	.07246	.05781	.04129
WOFC9	.22692	.18306	.13495	.11420	.09207	.06838	.05515	.04047
WOFC10	.23510	.18023	.12294	.09973	.07638	.05361	.04176	.02933
PCPC	5190.95874	3597.55630	2186.55225	1685.20627	1218.83098	788.66866	583.22816	384.12576
PTIT	5049.89966	3499.79633	2127.13489	1639.41248	1185.71046	767.23738	567.37952	373.68752
PTE	3020.00000	2245.15240	1488.20470	1190.05440	894.47815	602.77700	456.18209	309.16123
RPT	1.67215	1.55682	1.42933	1.37759	1.32559	1.27284	1.24376	1.20871
MR/C	10.40762	12.13002	14.37540	15.50491	16.83223	18.12694	19.11988	22.53152
TGPC	1400.10164	1154.81873	916.72253	822.14769	727.31473	646.87016	595.19215	503.27549
RGPC	47.59236	45.01923	42.25354	41.08126	39.87002	38.85803	38.16378	33.04282
KGPC	1.25221	1.24711	1.24098	1.23996	1.24149	1.24654	1.25272	1.25858
C*PCTH	2562.78549	2325.73523	2004.05545	1983.66655	1879.70274	1759.12054	1728.12715	1533.81288
WL/WT	.00000	.04618	.18324	.24158	.30387	.36682	.40782	.48758
MRTI	10.40762	11.52373	11.55809	11.51761	11.41363	11.11071	10.91466	11.05808
TTIT	1400.10164	1219.46159	1175.66423	1165.96980	1164.45190	1187.39537	1205.10089	1181.92430
RGTI	47.59236	45.99496	46.27354	46.46309	46.75576	47.40097	47.81301	47.59564
KGTI	1.25221	1.25047	1.25410	1.25568	1.25753	1.26038	1.26202	1.26176
ATGAS	1.64757	1.64178	1.63102	1.62945	1.62970	1.63262	1.63466	1.63560
CTI	1667.82885	1452.92343	1295.35309	1227.71542	1156.84329	1087.33424	1045.16733	966.72054
U/C-GT	.48399	.45312	.38519	.35100	.[illegible]96	.25847	.22723	.19475
TTET	1267.62222	1057.41878	852.52657	770.03288	686.5[illegible]9	616.75777	570.64542	484.34471

CASE 1 NOM BAL 50K 4-3-69
CASE 2 THROTTLE W/ FPCV, F=37500
CASE 3 THROTTLE W/ FPCV, F=25000
CASE 4 THROTTLE W/ FPCV, F=20000
CASE 5 THROTTLE W/ FPCV, F=15000
CASE 6 THROTTLE W/ FPCV, F=10000
CASE 7 THROTTLE W/ FPCV, F=7500
CASE 8 THROTTLE W/ FPCV, F=5000

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TABLE A-II

Engine Parameter Symbols

UNITS: LB, PSI, PSIA, SEC, LB/SEC, RPM, °F, IN^2, LB/FT^3

F	THRUST
PCSC	SECONDARY COMBUSTOR CHAMBER PRESSURE, TOTAL AT THROAT
MR-ENG	ENGINE MIXTURE RATIO
IS	SPECIFIC IMPULSE
W-ENG	ENGINE PROPELLANT FLOW RATE
WOT	ENGINE OXIDIZER FLOW RATE
WFT	ENGINE FUEL FLOW RATE
NT	TURBINE SPEED
TTIT	TURBINE INLET TEMPERATURE - TOTAL
RPT	TURBINE PRESSURE RATIO - TOTAL TO STATIC
POEIT	ENGINE INLET PRESSURE, OXIDIZER-TOTAL
TOEIT	OXIDIZER TEMPERATURE AT INLET
PFEIT	ENGINE INLET PRESSURE, FUEL-TOTAL
TFEIT	FUEL TEMPERATURE AT INLET
ATSC	SECONDARY COMBUSTOR THROAT AREA
ATT	TURBINE AREA
ATT*	TURBINE CHARACTERISTIC AREA
ATOBP	OXIDIZER BOOST PUMP TURBINE AREA
ATFBP	FUEL BOOST PUMP TURBINE AREA
KWFSCV	SECONDARY COMBUSTOR FUEL VALVE ADMITTANCE, $IN-LB^{1/2}/SEC$
KWFPCV	PRIMARY COMBUSTOR FUEL VALVE ADMITTANCE, $IN-LB^{1/2}/SEC$
CSFOR	SECONDARY FUEL ORIFICE RESISTANCE SEC^2/FT^5
CPFOR	PRIMARY FUEL ORIFICE RESISTANCE SEC^2/FT^5
CPOOR	PRIMARY OXIDIZER ORIFICE RESISTANCE SEC^2/FT^5
COBTOR	OXIDIZER BOOST PUMP TURBINE ORIFICE RESISTANCE SEC^2/FT^5
CFBTOR	FUEL BOOST PUMP TURBINE ORIFICE RESISTANCE SEC^2/FT^5
KOFCT	TURBULANT ADMITTANCE FILM COOLING - SEC. COMB.
COFCL	LAMINAR RESISTANCE FILM COOLING CIRCUIT, $LB-SEC/FT^5$
KWOBY	ADMITTANCE OXIDIZER PUMP BYPASS $IN-LB^{1/2}/SEC$
KWFBY	ADMITTANCE FUEL PUMP BYPASS $IN-LB^{1/2}/SEC$
COFCT	TURBULENT RESISTANCE FILM COOLING CIRCUIT, $LB-SEC/FT^5$
DOFCOR	EQUIVALENT DIAMETER, FILM COOLING ORIFICE, IN.

TABLE A-II (cont.)

UNITS: LB/PSIA

F	THRUST
POT	OXIDIZER TANK PRESSURE AT OUTLET
POSTB	OXIDIZER PRESSURE BOOST PUMP SUCTION-TOTAL
POSB	OXIDIZER PRESSURE BOOST PUMP SUCTION-STATIC
PODB	OXIDIZER PRESSURE BOOST PUMP DISCHARGE-STATIC
POSTM	OXIDIZER PRESSURE MAIN PUMP SUCTION-TOTAL
POSM	OXIDIZER PRESSURE MAIN PUMP SUCTION-STATIC
PODM	OXIDIZER PRESSURE BOOST PUMP DISCHARGE-STATIC
POH	OXIDIZER PRESSURE HOUSING-STATIC
POJPC	OXIDIZER PRESSURE PRIMARY INJECTOR INLET-STATIC
PFT	FUEL TANK PRESSURE AT OUTLET
PFSTB	FUEL PRESSURE BOOST PUMP SUCTION-TOTAL
PFSB	FUEL PRESSURE BOOST PUMP SUCTION-STATIC
PFDB	FUEL PRESSURE BOOST PUMP DISCHARGE-STATIC
PFSTM1	FUEL PRESSURE MAIN PUMP 1 SUCTION-TOTAL
PFSM1	FUEL PRESSURE MAIN PUMP 1 SUCTION-STATIC
PFDM1	FUEL PRESSURE MAIN PUMP 1 DISCHARGE-STATIC
PSCOR	FUEL PRESSURE SECONDARY COMBUSTOR ORIFICE IN-STATIC
PSCV	FUEL PRESSURE SECONDARY COMBUSTOR VALVE IN-STATIC
PFSCM	FUEL PRESSURE SECONDARY INJECTOR MANIFOLD IN-STATIC
PFJSC	FUEL PRESSURE SECONDARY INJECTOR IN-STATIC
PFSTM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-TOTAL
PFSM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-STATIC
PFDM2	FUEL PRESSURE MAIN PUMP 2 DISCHARGE-STATIC
PFPOR	FUEL PRESSURE PRIMARY COMBUSTOR ORIFICE IN-STATIC
PFPCV	FUEL PRESSURE PRIMARY COMBUSTOR VALVE IN-STATIC
PFPCM	FUEL PRESSURE PRIMARY INJECTOR MANIFOLD IN-STATIC
PFJPC	FUEL PRESSURE PRIMARY INJECTOR IN-STATIC
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE
PTIT	TURBINE INLET PRESSURE-TOTAL
PTET	TURBINE EXIT PRESSURE-TOTAL
PTE	TURBINE EXIT PRESSURE-STATIC
PPI	DISTRIBUTION PLATE PRESSURE AT INLET
PPE	DISTRIBUTION PLATE PRESSURE AT EXIT
PCFACE	SECONDARY COMBUSTOR FACE PRESSURE
PCSC	SECONDARY COMBUSTOR PLENUM PRESSURE
PESC	NOZZLE EXIT PRESSURE

TABLE A-II (cont.)

UNITS: LB, LB/SEC, °F, PSI, RPM, LBS/FT^3, FT

F	THRUST
DP/PSF	(PFJSCT-PCFACE)/PCFACE
DP/PPO	(POJPCT-PCPC)/PCPC
DP/PPF	(PFJPCT-PCPC)/PCPC
PCSC	SECONDARY COMBUSTOR CHAMBER PRESSURE - TOTAL
MRSC	SECONDARY COMBUSTOR MIXTURE RATIO
AE/AT	AREA EXIT/AREA THROAT
ETAC	SECONDARY INJECTOR COMB. EFF.
ETAN	NOZZLE EFFICIENCY, %
C*SC	SECONDARY COMBUSTOR CHARACTERISTIC VELOCITY
CF	NOZZLE COEFFICIENT
WGJSC	GAS FLOW RATE, SECONDARY COMB.
WFJSC	FUEL FLOW RATE, SECONDARY COMB.
WOFC	OXIDIZER COOLANT FLOW RATE
WFC/WT	COOLANT/TOTAL PROPELLANT FLOW RATE
DPFJSC	ΔP, FUEL SECONDARY INJECTOR PFJSC-PCFACE
DPOFC	ΔP, OXIDIZER FILM COOLANT CIRCUIT POHT-POFCD
WOJPC	OXIDIZER FLOW RATE, PRIMARY COMBUSTOR
WFJPC	FUEL FLOW RATE, PRIMARY COMBUSTOR
MRPC	PRIMARY COMBUSTOR MIXTURE RATIO
TTIT	TURBINE INLET TEMPERATURE-TOTAL
KGPC	SPECIFIC HEAT RATIO, TURBINE GAS
RGPC	GAS CONSTANT, TURBINE GAS, FT/°R
C*PC	PRIMARY COMBUSTOR GAS C*, THEORETICAL AT MRPC, FT/SEC
HOB	OXIDIZER BOOST PUMP HEAD, RISE TOTAL
HFB	FUEL BOOST PUMP HEAD RISE TOTAL
HOM	OXIDIZER MAIN PUMP HEAD RISE TOTAL
HFM1	FUEL 1 MAIN PUMP HEAD RISE TOTAL
HFM2	FUEL 2 MAIN PUMP HEAD RISE TOTAL
NPSHOB	OXIDIZER BOOST PUMP NPSH - TOTAL
NPSHFB	FUEL BOOST PUMP NPSH - TOTAL
NPSHOM	OXIDIZER MAIN PUMP NPSH - TOTAL
NPSHFM	FUEL MAIN PUMP NPSH - TOTAL
NPSPOB	OXIDIZER BOOST PUMP NPSP - TOTAL
NPSPFB	FUEL BOOST PUMP NPSP - TOTAL
NPSPOM	OXIDIZER MAIN PUMP NPSP - TOTAL
NPSPFM	FUEL MAIN PUMP NPSP - TOTAL

TABLE A-II (cont.)

UNITS: LB, LB/SEC, RPM, °F, PSI, FT

F	THRUST
ETA-T	TURBINE EFFICIENCY
WTI	TURBINE WEIGHT FLOW
U/C-GT	TIP VELOCITY/SPOUTING VELOCITY, TURBINE
SHPT	TURBINE SHAFT HORSEPOWER
SHPOM	OXIDIZER PUMP SHAFT HORSEPOWER
SHPFM1	FUEL PUMP 1 SHAFT HORSEPOWER
SHPFM2	FUEL PUMP 2 SHAFT HORSEPOWER
RPT	TURBINE PRESSURE RATIO, TOTAL TO STATIC
POSTM	OXIDIZER PUMP SUCTION PRESSURE, TOTAL
PODTM	OXIDIZER PUMP DISCHARGE PRESSURE - TOTAL
HOMNC	OXIDIZER PUMP HEAD RISE, NONCAVITATING, TOTAL
QOSM	OXIDIZER PUMP VOLUME FLOW
HOM/N2	OXIDIZER PUMP/HEAD (SPEED)^2
Q/QDOM	OXIDIZER PUMP (Q/N)/(Q/N)D
ETA-OM	OXIDIZER PUMP EFFICIENCY
NSO	OXIDIZER PUMP SPECIFIC SPEED
SOM	OXIDIZER PUMP SUCTION SPECIFIC SPEED
D*OSM	OXIDIZER PUMP DENSITY, SUCTION
PFSTM1	FUEL PUMP 1 SUCTION PRESSURE - TOTAL
PFDTM1	FUEL PUMP 1 DISCHARGE PRESSURE - TOTAL
HFMNC1	FUEL PUMP 1 HEAD RISE, NONCAVITATING - TOTAL
QFSM1	FUEL PUMP 1 VOLUME FLOW
HF1/N2	FUEL PUMP 1 HEAD/(SPEED)^2
Q/QDF1	FUEL PUMP 1 (Q/N)/(Q/N)D
ETAFM1	FUEL PUMP 1 EFFICIENCY
NSF-1	FUEL PUMP 1 SPECIFIC SPEED
SFM1	FUEL PUMP 1 SUCTION SPECIFIC SPEED
D*FM1	FUEL PUMP 1 DENSITY, SUCTION
PFSTM2	FUEL PRESSURE MAIN PUMP 2 SUCTION-TOTAL
PFDTM2	FUEL PRESSURE MAIN PUMP 2 DISCHARGE-TOTAL
HFMNC2	HEAD RISE FUEL PUMP 2, NONCAVITATING - TOTAL
QFSM2	FUEL PUMP 2 VOLUME FLOW
HF2/N2	FUEL PUMP 2 HEAD/(SPEED)^2
Q/QDF2	FUEL PUMP 2 (Q/N)/(Q/N)D
ETAFM2	FUEL PUMP 2 EFFICIENCY
NSF-2	FUEL PUMP 2 SPECIFIC SPEED
NT	TURBINE SPEED

TABLE A-II (cont.)

UNITS: LB, RPM, LB/SEC, ^{o}F, $FT/LB/IN^2$

F	THRUST
NTOB	OXIDIZER BOOST PUMP SPEED
WOSB	OXIDIZER BOOST PUMP FLOW RATE
TOSB	OXIDIZER BOOST PUMP SUCTION TEMPERATURE
POSTB	OXIDIZER BOOST PUMP SUCTION PRESSURE-TOTAL
PODTB	OXIDIZER BOOST PUMP DISCHARGE PRESSURE-TOTAL
HOBNC	OXIDIZER BOOST PUMP HEAD RISE-NONCAVITATING, FT.- TOTAL
QOSB	OXIDIZER BOOST PUMP VOLUME FLOW, GPM
HOB/N2	OXIDIZER BOOST PUMP $HEAD/(SPEED)^2$
Q/QDOB	OXIDIZER BOOST PUMP (Q/N)/(Q/N)D
ETAOB	OXIDIZER BOOST PUMP EFFICIENCY
SHPOB	OXIDIZER BOOST PUMP SHAFT HORSEPOWER
SOB	OXIDIZER BOOST PUMP SUCTION SPECIFIC SPEED
PTITOB	OXIDIZER BOOST PUMP TURBINE INLET PRESSURE - TOTAL
DPTOB	OXIDIZER BOOST PUMP TURBINE ΔP - TOTAL TO STATIC
TTITOB	OXIDIZER BOOST PUMP TURBINE INLET TEMPERATURE
WTOB	OXIDIZER BOOST PUMP TURBINE FLOW RATE
ETATOB	OXIDIZER BOOST PUMP TURBINE EFFICIENCY
NTFB	FUEL BOOST PUMP SPEED
WFSB	FUEL BOOST PUMP FLOW RATE
TFSB	FUEL BOOST PUMP SUCTION TEMPERATURE
PFSTB	FUEL BOOST PUMP SUCTION PRESSURE-TOTAL
PFDTB	FUEL BOOST PUMP DISCHARGE PRESSURE-TOTAL
HFBNC	FUEL BOOST PUMP HEAD RISE-NONCAVITATING, FT.- TOTAL
QFSB	FUEL BOOST PUMP VOLUME FLOW, GPM
HFB/N2	FUEL BOOST PUMP $HEAD/(SPEED)^2$
Q/QDFB	FUEL BOOST PUMP (Q/N)/(Q/N)D
ETAFB	FUEL BOOST PUMP EFFICIENCY
SHPFB	FUEL BOOST PUMP SHAFT HORSEPOWER
SFB	FUEL BOOST PUMP SUCTION SPECIFIC SPEED
PTITFB	FUEL BOOST PUMP TURBINE INLET PRESSURE- TOTAL
DPTFB	FUEL BOOST PUMP TURBINE ΔP- TOTAL TO STATIC
TTITFB	FUEL BOOST PUMP TURBINE INLET TEMPERATURE
WTFB	FUEL BOOST PUMP TURBINE FLOW RATE
ETATFB	FUEL BOOST PUMP TURBINE EFFICIENCY
WOTS	OXIDIZER FLOW FROM BEARINGS TO TURBINE
WOBY	OXIDIZER BYPASSED TO SUCTION FOR BALANCE
WFBY	FUEL BYPASSED TO SUCTION FOR BALANCE
WFRTS	FUEL RETURN TO SUCTION

TABLE A-II (cont.)

UNITS: LBS, PSI, LB/FT^3, LBS/SEC, °F

F	THRUST
POT	OXID TANK PRESSURE AT OUTLET - TOTAL
DPOEI	ΔP TANK TO ENGINE INLET - TOTAL TO STATIC
POEIT	OXID PRESSURE AT ENGINE INLET - TOTAL
POEI	OXID PRESSURE AT ENGINE INLET - STATIC
DPOSB	ΔP ENGINE INLET TO BOOST PUMP SUCTION - S TO S
POSTB	BOOST PUMP SUCTION PRESSURE - TOTAL
POSB	BOOST PUMP SUCTION PRESSURE - STATIC
PODTB	BOOST PUMP DISCHARGE PRESSURE - TOTAL
PODB	BOOST PUMP DISCHARGE PRESSURE - STATIC
DPOSM	ΔP BOOST PUMP DISC. TO MAIN PUMP SUCTION - S TO S
POSTM	OXID PUMP SUCTION PRESSURE - TOTAL
POSM	OXID PUMP SUCTION PRESSURE - STATIC
PODTM	OXID PUMP DISCHARGE PRESSURE - TOTAL
PODM	OXID PUMP DISCHARGE PRESSURE - STATIC
DPOH	ΔP OXID HOUSING - STATIC TO STATIC
POHT	OXID HOUSING PRESSURE - TOTAL
POH	OXID HOUSING PRESSURE - STATIC
DPOORF	ΔP OXIDIZER HOUSING ORIFICE - STATIC TO STATIC
POJPCT	PRIMARY INJECTOR OXID INLET PRESSURE - TOTAL
POJPC	PRIMARY INJECTOR OXID INLET PRESSURE - STATIC
DPOJPC	ΔP PRIMARY INJECTOR OXID CIRCUIT - S TO S
PCPC	PRIMARY INJECTOR PRESSURE
TOT	OXIDIZER TEMPERATURE IN TANK
D*OT	OXID DENSITY IN TANK
WOT	OXID TOTAL WEIGHT FLOW
WOSM	OXID FLOW RATE AT MAIN PUMP SUCTION
TODM	OXID TEMPERATURE AT MAIN PUMP DISCHARGE
D*ODM	OXID DENSITY AT MAIN PUMP DISCHARGE
WOPC	OXID FLOW RATE IN PRIMARY COMBUSTOR
WOFC	OXID FLOW RATE TRANSPIRATION COOLANT
WTOB	OXID FLOW RATE BOOST PUMP TURBINE
WOTS	OXID FLOW RATE TURBINE SEAL
TOJPC	OXID TEMPERATURE AT PRIMARY INJECTOR INLET
D*OJPC	OXID DENSITY AT PRIMARY INJECTOR INLET
REOJPC	OXID REYNOLDS NUMBER IN PRIMARY INJECTOR
REFJSC	FUEL REYNOLDS NUMBER IN SECONDARY INJECTOR

S TO S STATIC TO STATIC

TABLE A-II (cont.)

UNITS: LBS, PSI, °F, LB/FT^3, LB/SEC

F	THRUST
PFT	FUEL TANK PRESSURE AT OUTLET - TOTAL
DPFEI	ΔP FUEL TANK TO ENGINE INLET - STATIC TO STATIC
PFEIT	FUEL PRESSURE AT ENGINE INLET - TOTAL
PFEI	FUEL PRESSURE AT ENGINE INLET - STATIC
DPFSB	ΔP ENGINE INLET TO BOOST PUMP SUCTION - S TO S
PFSTB	FUEL BOOST PUMP SUCTION PRESSURE - TOTAL
PFSB	FUEL BOOST PUMP SUCTION PRESSURE - STATIC
PFDTB	FUEL BOOST PUMP DISCHARGE PRESSURE - TOTAL
PFDB	FUEL BOOST PUMP DISCHARGE PRESSURE - STATIC
DPFSM	ΔP BOOST PUMP TO MAIN PUMP SUCTION - S TO S
PFSTM	FUEL PUMP 1 SUCTION PRESSURE - TOTAL
PFSM	FUEL PUMP 1 SUCTION PRESSURE - STATIC
PFDTM1	FUEL PUMP 1 DISCHARGE PRESSURE - TOTAL
PFDM1	FUEL PUMP 1 DISCHARGE PRESSURE - STATIC
DPSCL	ΔP SECONDARY COMBUSTOR FUEL LINE - S TO S
PSCORT	PRESSURE UPSTREAM OF SECONDARY FUEL ORIFICE-TOTAL
PSCOR	PRESSURE UPSTREAM OF SECONDARY FUEL ORIFICE-STATIC
DPSCOR	ΔP ORIFICE - STATIC TO STATIC
PSCVT	PRESSURE UPSTREAM OF SCFCV - TOTAL
PSCV	PRESSURE UPSTREAM OF SCFCV - STATIC
DPSCV	ΔP VALVE - STATIC TO STATIC
PFSCMT	PRESSURE UPSTREAM OF SEC. COMB. MANIFOLD - TOTAL
PFSCM	PRESSURE UPSTREAM OF SEC. COMB. MANIFOLD - STATIC
DPFSCM	ΔP MANIFOLD - STATIC TO STATIC
PFJSCT	INJECTOR INLET PRESSURE - TOTAL
PFJSC	INJECTOR INLET PRESSURE - STATIC
DPFJSC	ΔP FUEL INJECTOR - STATIC TO STATIC
PCFACE	CHAMBER PRESSURE AT INJECTOR FACE - STATIC
TFT	TEMPERATURE FUEL TANK
D*FT	FUEL DENSITY IN TANK
WFT	FUEL FLOW RATE FROM TANK
WFSM1	FUEL PUMP 1 FLOW RATE
TFDM1	TEMPERATURE AT FUEL PUMP 1 DISCHARGE
D*FDM1	DENSITY AT FUEL PUMP 1 DISCHARGE
WFSM2	FUEL PUMP 2 FLOW RATE
WFJSC	SECONDARY COMBUSTOR FUEL FLOW RATE
TFJSC	SECONDARY COMBUSTOR FUEL TEMPERATURE
D*FJSC	SECONDARY COMBUSTOR FUEL DENSITY

S TO S STATIC TO STATIC

TABLE A-II (cont.)

UNITS: LB, PSI, °F, LB/FT^3, LB/SEC

F	THRUST
PFDTM1	FUEL PUMP 1 DISCHARGE PRESSURE-TOTAL
PFDM1	FUEL PUMP 1 DISCHARGE PRESSURE-STATIC
DPFSM2	ΔP FUEL PUMP 1 DISCHARGE TO FUEL PUMP 2 SUCTION - S TO S
PFSTM2	FUEL PUMP 2 SUCTION PRESSURE-TOTAL
PFSM2	FUEL PUMP 2 SUCTION PRESSURE-STATIC
PFDTM2	FUEL PUMP 2 DISCHARGE PRESSURE-TOTAL
PFDM2	FUEL PUMP 2 DISCHARGE PRESSURE-STATIC
DPFPCL	ΔP PRIMARY COMBUSTOR FUEL LINE - STATIC TO STATIC
PFPORT	ORIFICE INLET PRESSURE-TOTAL
PFPOR	ORIFICE INLET PRESSURE-STATIC
DPFPOR	ΔP ORIFICE - STATIC TO STATIC
PFPCVT	PCFCV INLET PRESSURE-TOTAL
PFPCV	PCFCV INLET PRESSURE-STATIC
DPFPCV	ΔP PCFCV - STATIC TO STATIC
PFPCMT	PRIMARY INJECTOR MANIFOLD INLET PRESSURE-TOTAL
PFPCM	PRIMARY INJECTOR MANIFOLD INLET PRESSURE-STATIC
DPFPCM	ΔP MANIFOLD - STATIC TO STATIC
PFJPCT	PRIMARY INJECTOR FUEL INLET PRESSURE-TOTAL
PFJPC	PRIMARY INJECTOR FUEL INLET PRESSURE-STATIC
DPFJPC	ΔP PRIMARY INJECTOR - STATIC TO STATIC
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE -STATIC
TFSM2	TEMPERATURE FUEL PUMP 2 SUCTION
D*FSM2	DENSITY FUEL PUMP 2 SUCTION
WFSM2	FLOW RATE FUEL PUMP 2
TFDM2	TEMPERATURE FUEL PUMP 2 DISCHARGE
D*FDM2	DENSITY FUEL PUMP 2 DISCHARGED
WFPCJ	PRIMARY INJECTOR FUEL FLOW RATE
WFRTS	FUEL FLOW RETURN TO SUCTION
TFJPC	PRIMARY INJECTOR FUEL TEMPERATURE
D*FJPC	PRIMARY INJECTOR FUEL DENSITY
REEJPC	PRIMARY INJECTOR FUEL REYNOLDS NUMBER

TABLE A-II (cont.)

UNITS: LB, PSI, °F, LB/SEC, LB/FT^3

F	THRUST
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE - STATIC
DPPC	ΔP PRIMARY COMBUSTOR - STATIC TO TOTAL
PTIT	TURBINE INLET PRESSURE-TOTAL
PTET	TURBINE EXIT PRESSURE-TOTAL
PTE	TURBINE EXIT PRESSURE-STATIC
DPTX	ΔP TURBINE EXHAUST PASSAGE - STATIC TO STATIC
PPIT	DISTRIBUTION PLATE INLET PRESSURE-TOTAL
PPI	DISTRIBUTION PLATE INLET PRESSURE-STATIC
DPPI	ΔP DISTRIBUTION PLATE - STATIC TO STATIC
PPET	DISTRIBUTION PLATE EXIT PRESSURE-TOTAL
PPE	DISTRIBUTION PLATE EXIT PRESSURE-STATIC
DPJHG	ΔP SECONDARY INJECTOR GAS PASSAGE - S TO S
PCFACE	SECONDARY COMBUSTOR CHAMBER PRESSURE FACE - STATIC
PCSC	THRUST CHAMBER PRESSURE - TOTAL AT THRUST
PESC	SECONDARY COMBUSTOR EXIT PRESSURE-STATIC
TGPC	PRIMARY COMBUSTOR GAS TEMPERATURE BASED ON MRPC (SEE PAGE 10)
WPC	PRIMARY COMBUSTOR GAS FLOW RATE
TTIT	TURBINE INLET TEMPERATURE - TOTAL BASED ON MRTI (SEE PAGE 10)
TTET	TURBINE EXIT TEMPERATURE - TOTAL BASED ON MRPC
TJHGT	TEMPERATURE IN TURBINE EXHAUST PASSAGE
WJHG	FLOW RATE IN TURBINE EXHAUST PASSAGE
PODTM	OXIDIZER PUMP DISCHARGE PRESSURE-TOTAL
POFCI	TRANSPIRATION COOLANT INLET PRESSURE - STATIC
DPOFCL	ΔP TRANSPIRATION COOLANT PASSAGE - S TO S
POJFCT	TRANSPIRATION COOL CHAMBER MANIFOLD PRESSURE-TOTAL
PLJFC	TRANSPIRATION COOL CHAMBER MANIFOLD PRESSURE-STATIC
DPOJFC	ΔP TRANSPIRATION COOL CHAMBER PASSAGES - S TO S
POFCD	PRESSURE AT EXIT OF TRANSPIRATION COOL PASSAGES-STATIC
WOFC	TRANSPIRATION COOL FLOW RATE
TOFC	TRANSPIRATION COOL TEMPERATURE IN CHAMBER MANIFOLD
D[illegible]OJFC	TRANSPIRATION COOL DENSITY IN CHAMBER MANIFOLD
S TO S	STATIC TO STATIC

TABLE A-II (cont.)

UNITS: LB, LB/SEC, PSIA, LB/FT^3, ^{o}F, $FT/^{o}R$, FT/SEC

F	THRUST
WFC/WT	TRANSPIRATION COOLANT (TC) FRACTION
WOFC	TC FLOW RATE
POFCI	PRESSURE AT TC INLET
POFCDO	PRESSURE AT DISCHARGE OF TC ORIFICE
D*OFC	TC DENSITY
WOFCX	TC FLOW RATE THROUGH CIRCUIT X; X = 1-10
PCPC	PRIMARY COMBUSTOR CHAMBER PRESSURE
PTIT	TURBINE INLET PRESSURE, TOTAL
PTE	TURBINE EXIT PRESSURE, STATIC
RPT	TURBINE PRESSURE RATIO
MRPC	PRIMARY COMBUSTOR (PC) MIXTURE RATIO
TGPC	PC GAS TEMPERATURE, OMR (1)
RGPC	PC GAS CONSTANT, OMR
KGPC	SPECIFIC HEAT RATIO, PC, OMR
C*PCTH	THEORETICAL CHARACTERISTIC VELOCITY, PC, OMR
WL/WT	LIQUID FRACTION IN PC PRODUCTS
MRTI	MIXTURE RATIO OF GASSIFIED PRODUCTS IN PC
TTIT	TURBINE INLET TEMPERATURE, TOTAL GMR (2)
RGTI	GAS CONSTANT, PC, GMR
KGTI	SPECIFIC HEAT RATIO, PC, GMR
ATGAS	TURBINE AREA AVAILABLE FOR GAS FLOW
CTI	TURBINE SPOUTING VELOCITY, GMR
U/C-GT	TIP VELOCITY/SPOUTING VELOCITY, TURBINE, GMR
TTET	TURBINE EXIT TEMPERATURE, OMR

(1) OMR - THESE GAS PROPERTIES ARE BASED ON OVER-ALL MRPC

(2) GMR - THESE GAS PROPERTIES ARE BASED ON GASSIFIED PRODUCTS ONLY (MRTI)

III, A, Steady State (cont.)

(U) The two fuel control valves perform three functions: (1) propellant phasing during start and shutdown is controlled by sequencing both the primary and secondary fuel control valves, (2) engine thrust is controlled by the primary combustor fuel control valve, and (3) engine mixture ratio is established by the preset open position of the secondary combustor fuel control valve.

B. THROTTLING AND OFF-DESIGN OPERATION

(U) The engine is throttled by varying the position of the primary combustor fuel control valve. The mechanism by which the primary combustor fuel valve controls the thrust is as follows: increasing the resistance in this valve reduces the fuel flow to the primary combustor, which in turn reduces turbine temperature and, to a lesser extent, the turbine mass flow. The reduction in turbine drive energy results in decreased turbopump speed, pump discharge pressures, propellant flow rate, and thrust. A plot showing several engine parameter variations during throttling is shown in Figure A-5. The engine system maintains nearly constant mixture ratio during throttling because the designed relationship between fuel and oxidizer pump heads almost exactly compensate for the other factors that influence engine mixture ratio.

(C) The throttling depth of an engine is normally limited by the injectors. As the engine is throttled to lower thrust, injector stiffness ($\Delta P/P_c$) decreases and at some throttling depth a feed-system-coupled instability may develop. The thrust level at which the instability develops must be determined experimentally on any given system. The purpose of the Throttling Primary Injector Program was to determine the throttling depth achievable with a platelet injector, with a program goal of demonstrating 10:1 throttling. The effect on the engine of the program test results can be briefly summarized as follows:

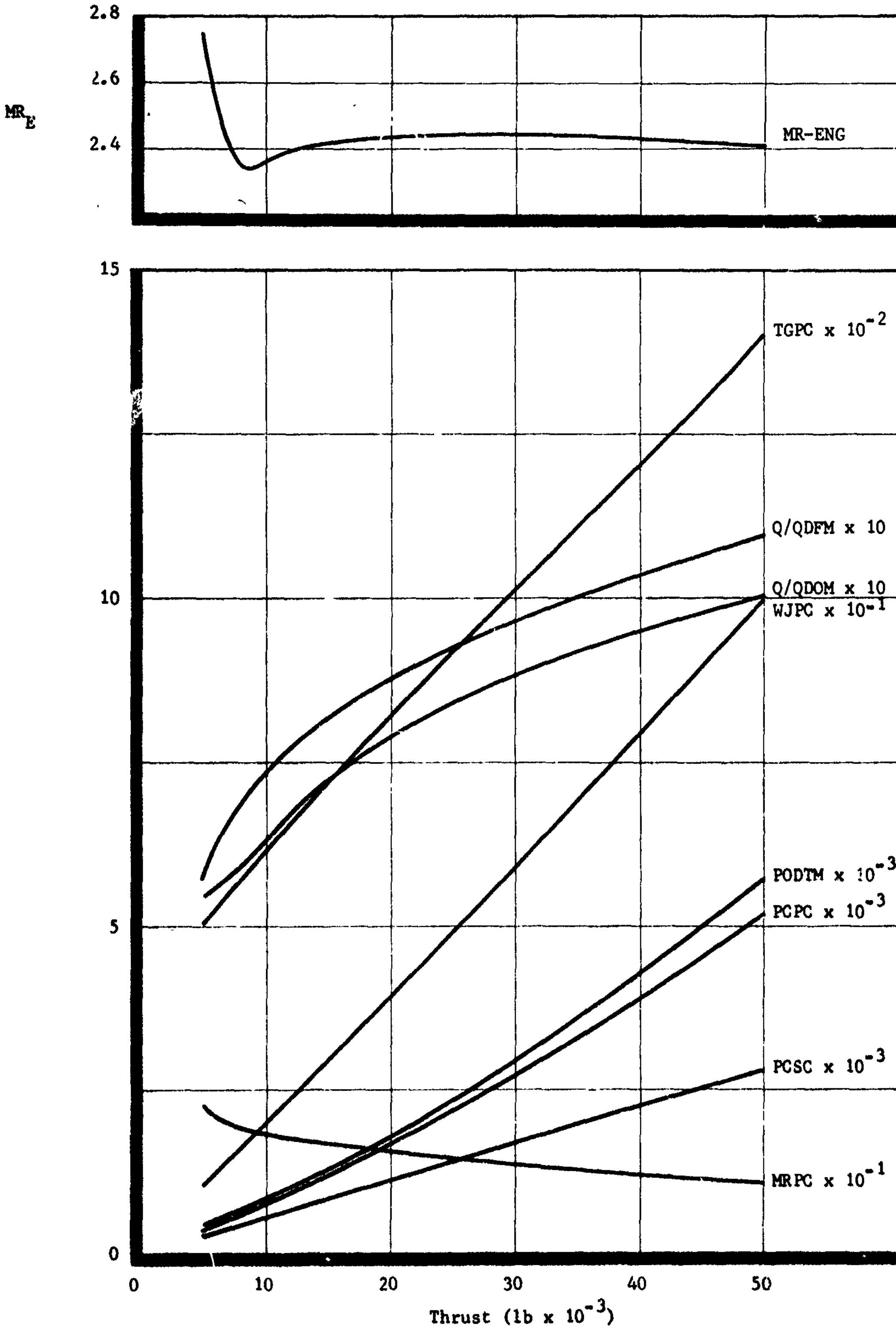

Figure A-5. MIST Throttling Parameters (U)

III, B, Throttling and Off-Design Operation (cont.)

(C) The initial design, which is compatible with the pressure drops in Table A-I, showed smooth operation above an equivalent thrust level of approximately 18K. The subsequent higher pressure drop design exhibited stable operation when throttled to approximately 8K lb. Use of this higher pressure drop injector requires that thrust chamber pressure be dropped from 2800 psia to 2400 psia. The detailed engine parameters for the 2400 psi engine are shown in Table A-III. The dual manifold design exhibited capability to achieve stable operation down to 5K. Use of this design requires throttling of the oxidizer as well as the fuel circuit.

(U) The dual manifold injector requires engine modification as follows: an additional primary combustor fuel circuit must be added, and fuel throttling accomplished by use of two valves or a dual sleeve valve. Similarly, two oxidizer circuits are needed with a valve incorporated in one of these circuits. It is quite apparent from inspecting the design that the additional fuel circuit and valve would not greatly alter the engine overall design. However, considerable additional design effort is needed to determine how best to incorporate the additional oxidizer circuit and valve. This effort has not been accomplished to date.

C. START AND SHUTDOWN

(U) The engine starts from tank pressure. No auxiliary start system is needed. Therefore, the engine is inherently restartable. Engine start is initiated by opening the suction valves. These valves are sequenced in such a manner as to assure an oxidizer lead to approximately 5% of design admittance. Primary combustor ignition occurs and the turbopump accelerates. When the first stage fuel pump pressure reaches 150 psia, the secondary combustor fuel control valve opens to its operating point position. After ignition in the secondary combustor, the primary combustor fuel control valve is opened to the desired thrust position at a rate to assure a smooth rapid start.

(U) The shutdown operation is the reverse of the startup operation and ends with all engine valves closed.

TABLE A-III

ENGINE PARAMETERS, FINAL (U)

PAGE 1	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70850	28005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19012
PCSC	2400.05502	1800.04128	1203.34583	964.80247	726.63203	490.09726	371.87492	283.39643
MR-ENG	2.42207	2.40618	2.40608	2.40742	2.41854	2.41623	2.42884	2.50932
IS	336.73265	335.26353	332.89565	331.33841	328.82071	324.35288	320.02264	310.82436
W-ENG	148.47354	111.78568	75.11524	60.36034	45.59682	30.82068	23.43611	16.08687
WOT	105.08490	78.96531	53.06190	42.64653	32.25844	21.79927	16.60083	11.50343
WFT	43.38794	32.81782	22.05346	17.71472	13.33855	9.02210	6.83484	4.58460
NT	36937.50140	29646.48926	21962.23853	18760.36499	15427.26485	11906.02209	9962.10266	7764.01965
RPT	1.72064	1.56972	1.39300	1.32524	1.25902	1.19442	1.16117	1.12563
POFIT	51.01642	51.49754	51.83981	51.93958	52.01745	52.07404	52.09402	52.10836
TOEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
PFEIT	39.24320	39.93424	40.44843	40.60089	40.72249	40.81060	40.84304	40.86771
TFEIT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
ATSC	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900	10.84900
ATT	1.60920	1.60920	1.60920	*.60920	1.60920	1.60920	1.60920	1.60920
ATT*	1.76805	1.75707	1.77395	1.77692	1.75830	1.73130	1.70915	1.65461
ATOBP	.02765	.02765	.02765	.02765	.02765	.02765	.02765	.02765
ATFBP	.01280	.01280	.01280	.01280	.01280	.01280	.01280	.01280
KWFSCV	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065	2.70065
KWFPCV	.70073	.24296	.14264	.12109	.10113	.08084	.07020	.05816
CSFOR	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528	3103.22528
CPFOR	16111.01660	16111.01650	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660	16111.01660
CPOOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
COBTOR	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000	200787.00000
CFBTOR	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000	240233.00000
COFCT	216081.52965	217646.76553	218514.97852	219366.80273	220517.59378	222170.43945	223422.49609	225336.61133
DCFCOR	.24856	.24856	.24856	.24856	.24856	.24856	.24856	.24856
KWOBY	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
KWFBY	.15029	.15029	.15029	.15029	.15029	.15029	.15029	.15029
CTIME	4.70730	7.71460	7.74018	9.02530	5.74436	6.80680	8.81110	11.03300

CASE 1 NOM ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 2	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70850	28806.53662	19989.57910	14993.17786	9996.76636	7500.08569	5000.19012
POT	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000
POSTB	46.11210	48.85684	51.08248	51.65107	52.11833	52.48784	52.57771	52.66374
POSB	40.88577	48.87842	49.64354	50.74097	51.59760	52.22008	52.43981	52.59752
PODB	144.08698	121.40125	96.57510	87.01092	77.72767	69.03723	64.69973	60.31354
POSTM	133.08108	115.42628	93.80089	85.18446	76.65303	68.52210	64.38967	60.15709
POSM	102.01728	97.31087	85.44069	79.70290	73.44696	67.00061	63.48069	59.70282
PODM	5646.81483	3741.80367	2138.46616	1599.16142	1119.17493	704.39521	515.16963	336.83451
POH	5630.80778	3732.07384	2134.87021	1597.07123	1118.24028	704.28534	515.33200	337.17519
POJPC	5162.79626	3448.23380	1982.70766	1500.32852	1058.10815	665.11688	486.11354	317.35264
PFT	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000
PFSTB	31.47412	35.58955	38.65180	39.55977	40.28392	40.80867	41.00187	41.14878
PFSB	23.24209	30.81270	36.44591	38.11618	39.44831	40.41361	40.76902	41.03927
PFDB	97.33241	87.45850	73.48324	67.19023	60.45956	54.03584	50.69786	47.34732
PFSTM1	82.48261	78.35881	68.92272	64.05491	58.71433	53.01525	50.04469	46.99622
PFSM1	70.54534	71.22377	65.45081	61.70795	57.29123	52.29197	49.59261	46.76167
PFDM1	4061.24153	2841.28781	1721.34650	1315.10808	937.07378	594.47159	435.56913	285.11745
PSCDR	3637.57779	2579.22141	1595.49236	1232.23529	889.42511	572.65953	423.24484	279.87412
PSCV	3637.57775	2579.22141	1595.49236	1232.23329	889.42511	572.65953	423.24484	279.87412
PFSCM	3454.77884	2466.92026	1541.49753	1196.54121	868.73012	563.02940	417.71846	277.45408
PFJSC	2644.76013	1562.92720	1294.13070	1030.91237	770.88597	516.00585	389.88734	264.41442
PFSTM2	4022.87210	2820.96320	1713.48819	1310.57657	934.92804	593.90198	435.44601	285.24040
PFSM2	4022.43994	2820.75397	1713.38461	1310.52437	934.98847	593.88774	435.43725	285.23586
PFDM2	6634.69330	4893.30872	2720.08475	2052.59204	1441.01291	897.29736	648.40923	414.86488
PFPOR	6584.43170	4872.30640	2713.14847	2049.28619	1439.99226	856.99884	648.31438	415.04319
PFPCV	6523.60638	4861.48712	2717.75235	2054.90747	1444.96577	900.39874	650.76191	416.52775
PFPCM	6340.88843	3930.56488	2137.04089	1613.71713	1145.86432	726.88448	533.68031	349.65113
PFJPC	6334.88208	3927.97244	2136.21487	1613.26538	1145.65079	726.80533	533.64005	349.63535
PCPC	4658.22394	3161.76389	1852.08427	1407.09201	1003.00150	639.03477	470.61963	309.90113
PTIT	4528.72290	3066.11786	1801.75574	1368.85570	975.74593	621.66964	457.83102	301.47988
PTET	2646.82288	1561.72429	1257.68591	1036.10532	777.08727	521.97781	395.23149	268.47501
PTE	2632.00000	1553.29045	1293.43774	1032.90894	775.20138	520.47963	394.28372	267.83108
PPI	2633.11083	1583.21828	1293.07307	1032.74992	774.82166	520.62223	394.27142	267.88878
PPE	2527.24008	1888.52658	1258.44423	1007.69907	757.98448	510.60951	387.19447	263.58790
PCFACE	2477.19998	1857.89999	1242.02496	995.81412	749.98816	505.88045	383.52809	261.54135
PCSC	2400.65563	1880.84128	1203.34583	964.80247	726.63203	490.05726	371.87492	253.39643
PESC	.36488	.27247	.18261	.14667	.11103	.07488	.05705	.03932

CASE 1 NOR ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 3	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70450	25005.53662	19999.57910	14993.17786	9996.76636	7500.08869	5000.19012
DP/PSF	.09276	.07768	.05674	.04746	.03730	.02668	.02083	.01437
DP/PPC	.11528	.05927	.07995	.06969	.05770	.04277	.03445	.02514
DP/FPF	.36074	.24625	.15342	.14653	.14222	.13735	.13391	.12822
PCSC	2400.05802	1800.04128	1203.34583	964.60247	726.63203	490.09726	371.87492	283.39643
MRSC	2.19941	2.18676	2.19326	2.19807	2.21280	2.21252	2.22586	2.30496
AE/AT	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000	300.00000
ETAC	.99010	.98864	.98770	.98742	.98722	.98677	.98658	.98665
ETAN	.92813	.92285	.91656	.91263	.90630	.89416	.88268	.86106
C*SC	5642.43945	5620.70813	5591.87122	5579.32257	5562.86091	5550.53603	5538.67810	5498.24127
CF	1.92810	1.91911	1.91638	1.91070	1.90191	1.88013	1.85900	1.81885
WGJSC	104.33297	77.50179	51.60949	41.33881	31.14743	20.96880	15.93128	11.01841
WFJSC	34.48177	27.07636	18.81307	15.31499	11.88677	8.01857	6.11650	4.13466
WOFC	9.66886	7.20512	4.69321	3.70764	2.74411	1.83717	1.38782	.93573
WFC/WT	.06807	.06445	.06249	.06143	.06018	.05961	.05922	.05817
DPFJSC	167.86015	105.02721	52.10582	35.09825	20.89781	10.15540	6.05925	2.87307
DPOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
WOJPC	90.41835	67.86923	45.63865	36.88477	27.74008	18.63183	14.11823	9.71852
WFJPC	8.90617	5.74145	3.24039	2.39973	1.65177	1.00653	.71834	.44994
MRPC	10.15233	11.82893	14.08432	15.28703	16.79410	18.51068	19.64983	21.59973
TTIT	1421.99768	1218.22780	1151.47594	1129.89961	1112.55109	1116.05991	1125.58754	1129.88348
KGTI	1.25495	1.25222	1.25425	1.25600	1.25575	1.25749	1.25866	1.25956
RGTI	46.25864	46.26856	46.12690	46.09572	46.10140	46.40381	46.66662	46.84371
C*PC	2593.75916	2354.73236	2103.86975	1995.51961	1878.05109	1763.34465	1697.24390	1576.35330
HOB	162.58928	119.28327	74.50030	57.70248	41.66647	26.88547	19.62499	12.36599
HFB	191.77974	146.32612	95.49348	74.90520	54.60519	35.04071	25.52935	16.21195
HOM	8930.02747	5866.32831	3303.37167	2444.64728	1682.38280	1025.46225	726.69473	445.84826
HFM1	10524.28295	7273.85553	4329.86316	3270.52805	2290.86406	1409.36778	1001.96043	617.94895
HFM2	7274.96613	4824.82660	2693.59576	1973.67998	1338.38071	798.14662	558.77676	339.18661
NPSHOE	45.83370	50.48789	53.79863	54.76361	55.81686	56.06417	56.25741	56.39609
NPSHFE	73.81775	84.38207	92.24313	94.57380	96.43262	97.77956	98.27849	98.65259
NPSHOM	184.43583	155.679[illegible]	121.43968	107.77127	94.23125	81.31879	74.76017	68.06669
NPSHFM	203.98404	193.5[illegible]	169.40694	156.92949	143.23179	128.60131	120.96806	113.11106
NPSPOE	28.48810	31.3[illegible]288	33.44083	34.04092	34.50934	34.84970	34.96987	35.05611
NPSPFE	28.75857	32.87525	35.93842	36.84667	37.57104	38.09594	38.28920	38.43616
NPSPOM	114.34234	96.59018	75.39492	66.92301	58.82631	50.51288	46.44487	42.29167
NPSPFM	79.81778	79.87365	65.76791	60.94353	55.63859	49.96438	46.99902	43.94512

CASE 1 NOM ENG 6-29-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 4	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.84195	37477.70850	25005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19018
ETA-T	.72684	.72290	.70590	.69323	.67382	.64031	.61311	.57309
WTI	99.32452	73.81068	48.87904	39.08451	29.39186	19.63806	14.83357	10.16845
U/C-GT	.46503	.44080	.38692	.35027	.32864	.28681	.25967	.22623
SHPT	6124.72150	3140.23792	1258.09045	775.08546	423.48787	189.86432	109.57802	50.97098
SHPDM	3090.62933	1863.66039	619.53061	380.61557	208.88566	93.39669	53.91601	25.11889
SHPFM1	2469.34183	1301.86244	528.32220	326.11673	177.75975	79.07643	45.31964	20.91488
SHPFM2	544.67074	275.27982	110.22132	68.38313	37.93313	17.47274	10.28867	4.92788
RPT	1.72064	1.56972	1.39300	1.32524	1.25902	1.19442	1.[illegible]6117	1.12563
PCSTM	133.62105	115.42628	93.80089	85.18446	76.68303	68.52210	64.38967	60.15709
PODTM	5669.94238	3755.15628	2144.67584	1603.24342	1121.56772	705.53289	515.84985	337.17467
HOMNC	8931.16884	5866.36902	3303.35080	2444.64725	1682.40962	1025.45938	726.78646	445.84858
QOSM	582.68131	440.55910	299.19135	242.24086	185.24222	127.60084	98.62244	69.71632
HOM/N2	-5 65459733	-5 66772654	-5 68485949	-5 69459815	-5 70689330	-5 72341096	-5 73232657	-5 73962934
Q/QDOM	1.00813	.94706	.86802	.82274	.76509	.68288	.63079	.57214
ETA-OM	.60890	.59824	.57779	.56363	.54266	.50771	.48175	.44852
NSO	970.81260	928.13363	871.83677	839.85224	799.30078	742.17128	706.77928	668.12888
SOM	17815.75486	14116.49951	10384.67957	8729.71240	6942.64233	4966.76935	3891.33276	2738.65903
D*OSM	89.27426	89.34398	89.40138	89.42005	89.43726	89.45190	89.46021	89.47110
PFSTM1	82.45261	76.35881	68.92272	64.05491	58.71453	53.01525	50.04469	46.99622
PFDTM1	4159.38696	2900.07220	1749.96884	1334.45877	948.81109	600.43745	439.29848	2[illegible]7.05251
HFMNC1	10524.43[illegible]2	7273.85767	4329.86322	3270.52808	2290.56409	1409.36780	1001.96044	617.94598
QFSM1	479.77829	372.76984	261.47316	215.71807	168.80881	121.20132	96.32700	69.91978
HF1/N2	-5 77137181	-5 82793082	-5 89767879	-5 92925586	-5 96241988	-5 99423940	-4 10095981	-4 10251259
Q/QDF1	1.29468	1.25356	1.18670	1.14613	1.09067	1.01468	.96380	.89764
ETAFM1	.45849	.47154	.49532	.49012	.49293	.48961	.48271	.46822
NSF-1	778.64374	726.57716	665.32616	637.12000	605.38233	569.83897	549.01870	523.80995
SFM1	14991.69617	11028.89265	7563.17181	6214.67334	4841.37918	3432.40512	2680.66333	1871.84529
D*FM1	55.78982	55.85052	55.90431	55.92236	55.93701	55.94710	55.94887	55.94587
PFSTM2	4022.87210	2820.96320	1713.46819	1310.57657	934.98804	593.90198	435.44601	285.24040
PFDTM2	6842.01984	4893.54736	2759.92645	2077.53381	1455.13048	904.08624	652.88360	417.02662
HFMNC2	7274.96613	4824.82660	2693.59576	1973.67998	1338.38071	798.14662	558.77676	339.18661
QFSM2	99.47504	69.18745	43.63360	34.52075	25.98174	18.02630	14.13987	10.17926
HF2/N2	-5 53320711	-5 54917526	-5 55844345	-5 56078212	-5 56234364	-5 56308303	-5 56303617	-5 56268514
Q/QDF2	1.00381	.86968	.74054	.68587	.62778	.56438	.52905	.48869
ETAFM2	.30036	.27444	.24167	.22587	.20784	.18669	.17409	.15882
NSF-2	467.68283	425.78821	388.00551	372.24076	355.37628	336.63403	325.94551	313.41209
NT	36937.50146	29846.48926	21962.23853	18760.36499	15427.26489	11906.02209	9962.10266	7764.01968

CASE 1	NOM ENG 6-25-69
CASE 2	F=37500
CASE 3	F=25000
CASE 4	F=20000
CASE 5	F=15000
CASE 6	F=10000
CASE 7	F=7500
CASE 8	F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 5	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.84195	37477.70850	25005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19012
NTOB	12026.28874	9711.25110	7225.23096	6181.13727	5090.10504	3935.78830	3293.46411	2560.69843
WOSB	105.88490	78.96531	53.06190	42.64653	32.25844	21.79927	16.60083	11.80343
TOSB	77.00000	77.00000	77.30000	77.00000	77.00000	77.00000	77.00000	77.00000
POSTB	46.11219	48.95884	51.05248	51.65107	52.11833	52.46784	52.87771	52.66374
PODTB	147.17802	123.14249	97.36131	87.51878	78.01824	69.16995	64.77670	60.35050
HOBNC	162.89852	119.28327	74.50030	57.70248	41.66647	26.88847	19.62499	12.34899
QOSB	526.92908	395.94259	266.05248	213.82819	161.74169	109.29966	83.23498	57.67702
HOB/N2	-5 11241763	-5 12648212	-5 14271004	-5 15102808	-5 16081748	-5 17386178	-5 18092712	-5 18888707
Q/QDOB	1.17029	1.08901	.98353	.92400	.84873	.74176	.67504	.60161
ETAOB	.59717	.61637	.61162	.59839	.57338	.52653	.49146	.44755
SHPOB	52.02001	27.78515	11.75153	7.47709	4.26232	2.02381	1.20828	.57789
SOB	15672.24219	10202.85857	5932.92963	4489.97595	3182.96085	2008.34944	1482.79437	948.00769
PTITOB	3886.97698	2282.65321	1483.83824	1114.01776	784.76363	500.16201	370.28233	247.84202
DPTOB	3742.88555	2461.25221	1387.26314	1027.00684	707.83896	431.12477	305.58259	187.82947
TTITOB	100.96215	93.68339	87.26339	85.13576	83.15615	81.40992	80.80438	79.81232
WTOB	10.82073	8.73813	6.53730	5.61815	4.65680	3.63324	3.05778	2.39478
ETATOB	.44921	.44687	.44629	.44526	.44396	.44228	.44124	.43998
NTFB	13987.27821	11556.32923	8819.91016	7621.11719	6332.84962	4923.39734	4130.14429	3223.86899
WFSB	43.38794	32.81782	22.05346	17.71472	13.33858	9.02210	6.83484	4.88460
TFSB	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
PFSTB	31.47413	35.56985	38.65180	39.58977	40.28392	40.80867	41.00187	41.14878
PFDTB	106.18832	92.59798	75.85658	68.74340	61.85861	54.46089	50.94838	47.46514
HFBNC	191.80453	146.32930	95.49371	74.90526	54.60520	38.04071	25.82938	16.21198
QFSB	347.05883	262.53284	176.41765	141.70893	106.70128	72.17176	54.67483	36.67414
HFB/N2	-6 98037530	-5 10956976	-5 12275704	-5 12896594	-5 13616855	-5 14458833	-5 14966124	-5 15598416
Q/QDFB	1.10115	1.00887	.88758	.82510	.74769	.65048	.58742	.50479
ETAFB	.62516	.62852	.60241	.57923	.54396	.49144	.45346	[illegible]
SHPFB	24.20002	13.89155	6.35619	4.16515	2.43451	1.16963	.69960	.33800
SFB	10347.87634	6725.66168	3935.92566	2991.58490	2128.72772	1346.16229	978.44687	623.71788
PTITFB	3717.24891	2593.92862	1567.48898	1196.52083	852.13876	540.96346	397.00061	268.96140
DPTFB	3619.91348	2506.47089	1494.00574	1129.33060	791.47919	486.92761	346.30278	213.81409
TTITFB	109.94088	100.14447	91.88336	89.08603	86.67908	84.69279	83.92327	83.30336
WTFB	3.84683	3.20292	2.47386	2.15106	1.80085	1.41246	1.19112	.93843
ETATFB	.37055	.36947	.36752	.36644	.36510	.36381	.36283	.36139
WOTS	2.70211	2.85667	1.47714	1.22361	.96233	.72948	.60662	.47578
WOBY	1.20120	.94481	.66726	.55371	.43893	.32772	.26938	.20672
WFBY	1.10014	.85044	.58604	.47999	.37431	.27357	.22174	.16748
WFRTS	3.46215	2.87064	2.19863	1.90439	1.58804	1.24128	1.04466	.81908

CASE 1 NOM ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 6	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70850	26005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19012
POT	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000	51.50000
DPOEI	16.59013	9.09729	3.76683	2.21313	1.30033	.11908	-.19206	-.41535
POEIT	51.01643	51.49754	51.83961	51.93958	52.01745	52.07404	52.09402	52.10836
POEI	34.90587	42.40271	47.73317	49.28687	50.49967	51.38092	51.69206	51.91535
DPOSB	-5.87590	-3.67571	-1.91037	-1.45409	-1.09793	-.83912	-.74775	-.68217
POSTB	46.11210	48.05884	51.05246	51.65107	52.11833	52.45784	52.57771	52.66374
POSB	40.58577	45.87842	49.64354	50.74097	51.59760	52.22005	52.43981	52.59752
PODTB	147.17002	123.14249	97.36131	87.51878	78.81824	69.16995	64.77670	60.35080
PODB	144.08658	121.40129	96.57510	87.01092	77.72767	69.03723	64.69973	60.31354
DPOSM	42.06971	24.09043	11.13441	7.30802	4.28071	2.03662	1.21905	.61073
POSTM	133.68105	115.42628	93.80089	85.18446	76.85303	68.52210	64.38967	60.15709
POSM	102.01726	97.31087	85.44069	79.70290	73.44696	67.00061	63.48069	59.70282
PODTM	5669.94236	3755.15628	2144.67584	1603.24342	1121.56772	705.53289	515.84985	337.17467
PODM	5646.81482	3741.80307	2138.46616	1599.16142	1119.17493	704.39521	515.16963	336.83451
DPOH	19.55190	11.69067	4.85308	3.05949	1.68265	.70300	.37645	.16908
POHT	5644.58673	3740.97147	2138.51178	1599.42958	1119.59145	704.89593	515.68269	337.34153
POH	5630.50775	3732.97354	2134.87021	1597.07123	1118.24028	704.28534	515.33200	337.17519
DPOORF	467.71155	284.73975	142.16255	96.74571	60.13213	39.16879	29.21846	19.82256
POJPCT	5191.73657	3464.63867	2000.16425	1505.15186	1060.67215	666.36523	486.83062	317.69271
POJPC	5162.79620	3448.22380	1992.70766	1500.32552	1058.10815	665.11656	486.11354	317.35264
DPOJPC	507.57227	296.46991	140.62338	93.23351	55.10666	26.08179	15.49390	7.45150
PCPC	4655.22394	3151.76389	1852.08427	1407.09201	1003.00150	639.03477	470.61963	309.90113
TOT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
D*OT	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039	89.51039
WOT	105.08490	78.96531	53.06190	42.64653	32.25844	21.79927	16.60083	11.50343
WOSM	115.90563	87.70344	59.59928	48.25469	36.91524	25.43251	19.65861	13.89819
TODM	100.96215	93.58339	87.26339	85.13576	83.15615	81.40992	80.50438	79.51232
D*ODM	91.58796	90.80530	90.17273	89.96028	89.77806	89.62351	89.56157	89.51408
WOPC	90.41835	67.86923	45.63865	36.68477	27.74008	18.63183	14.11523	9.71852
WOFC	9.65486	7.20512	4.69321	3.70764	2.74411	1.83717	1.38782	.93573
WTOB	10.82073	8.73813	6.53730	5.61815	4.65680	3.63324	3.05778	2.39476
WOTS	2.30734	1.79445	1.28331	1.03369	.81328	.60129	.49109	.37420
TOJPC	106.63645	96.97423	88.91580	86.24601	83.82917	81.78902	80.76320	79.66950
D*OJPC	90.41620	90.11911	89.83935	89.73660	89.64270	89.54747	89.50978	89.48276
REDJPC	18223.89307	12818.91943	8170.79480	6453.22510	4802.67900	3183.16833	2395.49170	1637.63268
REFJSC	36064.98730	25864.56281	16550.26318	13091.82971	9743.81848	6547.08160	4956.14056	3328.84952

CASE 1 NOM ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16149 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 7	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.84195	37477.76880	25005.53662	19999.57910	14993.17786	9996.76636	7500.08869	5008.19012
PFT	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000	40.50000
DPFFI	5.48884	5.34262	2.25746	1.34270	.61313	.08446	-.11018	-.25820
PFEIT	39.24320	39.93424	40.44843	40.60089	40.72249	40.81060	40.84304	40.86771
PFEI	31.01116	38.15730	38.24254	39.15730	39.88687	40.41884	40.61018	40.75820
DPFSB	1 77650880	1 43446767	1 17968256	1 10411186	43866049	-2 19302368	-15803207	-28107500
PFSTB	31.47411	35.58555	38.65180	39.55977	40.28392	40.80867	41.00187	41.14878
PFSB	23.24205	30.81270	36.44591	38.11618	39.44831	40.41361	40.76902	41.03927
PFDTB	106.18932	52.59795	75.85658	68.74340	61.65861	54.46089	50.94838	47.46514
PFDB	97.33241	87.45850	73.48324	67.19023	60.65986	54.03884	50.69786	47.34732
DPFSM	26.78307	16.23473	8.03243	5.48228	3.28834	1.74388	1.10824	.88564
PFSTM	82.45261	78.38881	68.92272	64.09491	58.71483	53.01828	50.04469	46.99622
PFSM	70.24534	71.22377	65.45081	61.70795	57.29123	52.29197	49.59261	46.78167
PFDTM1	4159.38696	2500.67220	1749.96884	1334.45877	948.81109	600.43748	439.29848	287.06251
PFDM1	4061.24152	2441.25781	1721.34680	1315.10808	937.87378	594.47159	435.86913	285.11748
DPSCL	460.13486	282.87408	136 15807	90.08636	52.31893	24.48336	14.11760	6.29386
PSCORT	3699.42474	2617.26328	1613 2587	1244.37903	896.49439	575.98488	425.18105	280.78898
PSCOR	3637.57775	2579.22141	1595.49238	1232.23529	889.42811	572.48553	423.24484	279.87412
DPSCOR	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
PSCVT	3699.42474	2617.26328	1613.82587	1244.37903	896.49439	575.98488	425.18105	280.78898
PSCV	3637.57775	2579.22141	1595.49236	1232.23529	889.42811	572.65553	423.24484	279.87412
DPSCV	182.80225	112.30115	53.99483	35.69408	20.69499	9.63013	5.82638	2.42004
PFSCMT	3516.65141	2504.92807	1859.83704	1208.68758	875.80029	566.35468	419.65474	278.33898
PFSCM	3454.77854	2466.92026	1541.49753	1196.54121	868.73012	563.02940	417.71846	277.45408
DPFSCM	810.01841	203.99388	247.36674	165.62885	97.84418	47.02388	27.83112	13.03966
PFJSCT	2706.98373	2601.11194	1312.49780	1043.07091	777.86033	519.33204	391.82394	265.29936
PFJSC	2644.76013	1562.92720	1294.13078	1030.91237	770.88597	516.00888	389.88734	264.41442
DPFJSC	167.56015	105.82721	52.10582	35.09825	20.89781	10.18540	6.08925	2.87307
PCFACE	2477.19998	1857.89999	1242.02496	995.81412	749.98816	505.85048	383.82809	261.84138
TFT	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000	77.00000
D#FT	56.10392	56.10392	56.10392	56.10392	56.10392	56.10392	56.10392	56.10392
WFT	43.38794	32.81782	22.05346	17.71472	13.33888	9.02210	6.83484	4.58460
WFSM1	55.64070	46.38891	32.57014	26.87937	21.83979	15.10887	12.00844	8.71896
TFDM1	109.94086	100.14447	91.88336	89.08603	86.67908	84.69279	83.92327	83.30336
D#FDM1	55.82753	55.90326	55.95064	55.96180	55.94612	55.96404	55.95833	55.94983
WFSM2	12.36832	8.61288	5.43901	4.30412	3.23982	2.24778	1.76300	1.26899
WFJSC	34.48177	27.87638	18.81307	15.31499	11.66677	8.01887	6.11680	4.13464
TFJSC	117.97418	105.10248	94.29373	90.69236	87.62249	85.14268	84.18802	83.42637
D#FJSC	55.25662	55.55019	55.77874	55.84721	55.89884	55.93200	55.93951	55.94083

CASE 1	NOM ENG 6-25-69
CASE 2	F=37500
CASE 3	F=25000
CASE 4	F=20000
CASE 5	F=15000
CASE 6	F=10000
CASE 7	F=7500
CASE 8	F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 08000000

TABLE A-III (cont.)

PAGE 8	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
F	49996.04195	37477.70850	25005.53662	19999.57910	14993.17786	9996.76636	7500.08569	5000.19012
PFDTM1	4189.38696	2900.07220	1749.96884	1334.45877	948.81109	600.43745	439.29848	287.05251
PFDM1	4061.24182	2841.25781	1721.34650	1315.10808	937.07375	594.47159	435.56913	285.11745
DPFSM2	38.80157	20.50365	7.96169	4.58371	2.11527	.58365	.13188	-.11841
PFSTM2	4022.87210	2820.56320	1713.46819	1310.57657	934.92804	593.90198	435.44601	285.24040
PFSM2	4022.43594	2820.75357	1713.38461	1310.52437	934.98847	593.88774	435.43728	285.23586
PFDTM2	6842.81984	4893.54736	2759.92645	2077.53381	1455.13048	904.08624	652.58360	417.02662
PFDM2	6634.69330	4553.30872	2720.05475	2052.59204	1441.01291	897.29736	648.40923	414.86488
DPFPCL	50.15790	20.59943	6.34247	3.34299	1.42899	.34708	.03384	-.16367
PFPCRT	6791.82220	4672.58774	2753.02173	2074.22849	1484.10997	903.78775	652.48877	417.20493
PFPCR	6584.43170	4572.30640	2713.14847	2049.28619	1439.99226	896.99884	648.31438	415.04319
DPFFDF	60.82932	10.81927	-4.60388	-5.62128	-4.97351	-3.39690	-2.44753	-1.48457
PFPCVT	6631.24750	4606.86232	2731.90677	2062.66144	1448.63556	901.78703	651.45494	416.79952
PFPCV	6523.60638	4561.48712	2717.75235	2054.90747	1444.96577	900.39574	650.76191	416.52775
DPFPCV	182.71796	636.90305	580.71146	441.19034	299.10146	173.51129	117.08160	86.87662
PFPCMT	6448.65057	3975.33271	2151.24561	1621.49197	1149.54077	728.24718	534.37383	349.92301
PFPCM	6340.88843	3930.98468	2137.04089	1613.71713	1145.86432	726.88445	533.68031	349.65113
DPFPCM	6.33636	2.61163	.82602	.45178	.21353	.07912	.04026	.01578
PFJPCT	6334.62201	3928.86146	2136.22409	1613.27040	1145.65318	726.80621	533.64050	349.63553
PFJPC	6334.85206	3927.97244	2136.21487	1613.26535	1148.65079	726.80633	533.64005	349.63535
DPFJPC	1679.32813	776.20856	284.13060	206.17334	142.64929	87.77056	63.02041	39.73421
PCPC	4655.22394	3151.76389	1852.08427	1407.09201	1003.80180	639.03477	470.61963	309.90113
TFSM2	109.94086	100.14447	91.88336	89.08603	86.67905	84.69279	83.92327	83.30336
D*FSM2	55.80195	55.68846	55.94380	55.95732	55.96353	55.96282	55.95761	55.94919
WFSM2	12.36832	8.61208	5.43901	4.30412	3.23982	2.24778	1.76300	1.26899
TFDM2	141.10393	123.57886	107.38806	101.49595	96.06083	91.08969	88.78578	86.59445
D*FCM2	55.33853	55.49357	55.64639	55.70613	55.76253	55.81739	55.84355	55.86916
WFJPC	8.90617	5.74145	3.24039	2.39973	1.65177	1.00653	.71834	.44994
WFRTS	8.94408	7.49753	5.84420	5.10921	4.31235	3.43305	2.93782	2.37688
TFJPC	151.67984	[illegible].98173	111.72340	104.79330	98.21467	92.34983	89.65014	87.10371
D*FJPC	54.59216	[illegible]96969	55.33839	55.47872	55.60917	55.72760	55.78195	55.83287
REFJPC	6037.72601	3[illegible].77338	1712.23837	1205.16957	790.00573	459.79318	321.09640	196.97622

CASE 1 NOM ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16146 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

TABLE A-III (cont.)

PAGE 9	CASE 1	CASE 2	CASE 3	~~CASE 4~~	-CASE 5	CASE 6	CASE 7	CASE 8
F	49996.84199	37477.70850	25008.53662	19999.57910	14993.17786	9996.76636	7800.08569	5000.19012
PCPC	4685.22394	3181.76389	1852.08427	1407.09201	1003.80150	639.03477	470.61963	309.90113
DPPC	126.80104	85.64603	50.32854	38.23631	27.28586	17.36513	12.78862	8.42128
PTIT	4528.72390	3646.11786	1801.78874	1368.85570	978.74593	621.66964	457.83102	301.47988
PTET	2646.82288	1961.72429	1297.68591	1036.10532	777.08727	521.97751	395.23149	268.47801
PTE	2632.00080	1953.29045	1293.43774	1032.90894	775.00139	520.47963	394.28372	267.83108
DPTX	-1.11602	.07217	.36467	.15901	.17970	-.14260	.01230	-.05770
PPIT	2646.82288	1961.72429	1297.68591	1036.10532	777.08727	521.97751	395.23149	268.47801
PPI	2633.11002	1953.21828	1293.07307	1032.74992	774.82166	520.62223	394.27142	267.88878
DPPI	108.88990	64.69170	34.62885	25.05085	16.83717	10.01272	7.07696	4.30088
PPET	2541.92792	1897.32448	1263.18422	1011.13806	760.30043	511.99141	388.17208	264.18370
PPE	2827.24088	1888.52658	1258.44423	1007.69907	787.98448	510.60981	387.19447	263.88790
DPJHG	56.04007	30.62659	16.41927	11.88496	7.99632	4.75906	3.36637	2.04688
PCFACE	2477.19990	1857.89999	1242.02496	995.81412	749.08816	505.88048	383.82809	261.84138
PCSC	2400.05802	1800.84128	1203.34583	964.80247	726.63203	490.09726	371.17492	253.39643
PESC	.36428	.27247	.18261	.14667	.11102	.07468	.05705	.03932
TGPC	1421.99768	1178.98201	930.40718	829.23514	723.40942	624.10326	569.41061	517.92641
WPC	99.32452	73.61067	48.87904	39.08450	29.39185	19.63806	14.83357	10.16848
TTIT	1421.99768	1218.22780	1151.47594	1129.89961	1112.55109	1116.06991	1125.58754	1129.88348
TTET	1279.20880	1073.68693	865.69966	778.03331	684.75020	596.64697	547.44937	501.46020
TJHGT	1293.34590	1086.67923	879.29308	791.35146	696.72278	606.01482	554.10868	505.51033
WJHG	104.33351	77.50179	51.60949	41.33881	31.16743	20.96880	15.93128	11.01841
PODTM	5669.94238	3755.15628	2144.67584	1603.24342	1121.56772	705.53289	515.84985	337.17467
POFCI	5626.86293	3730.71240	2133.61316	1596.10193	1117.49228	703.69221	514.79318	336.67543
DPOFCL	1528.77765	881.83194	370.63261	232.77362	128.32388	58.09370	33.37012	15.28144
POJFCT	4098.08527	2866.88046	1762.98055	1363.32831	989.16843	645.59852	481.42306	321.39399
POJFC	4098.08527	2864.88046	1762.98055	1363.32831	989.16843	645.59852	481.42306	321.39399
DPOJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
POFCD	4098.08527	2866.88046	1762.98055	1363.32831	989.16843	645.59852	481.42306	321.39399
WOFC	9.86086	7.20812	4.69321	3.70764	2.74411	1.83717	1.38782	.93873
TOFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
D*OJFC	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

CASE 1 NOM ENG 6-25-69
CASE 2 F=37500
CASE 3 F=25000
CASE 4 F=20000
CASE 5 F=15000
CASE 6 F=10000
CASE 7 F=7500
CASE 8 F=5000

JOB 16145 REVISED 16 SEP. 69 DATE OF THIS RUN 16 SEPT 1969 00000000

CONFIDENTIAL

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3 REPORT TITLE

(Title Unclassified)

Throttlable Primary Injector for Staged Combustion Engine

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report (1 Nov 1968 through 15 December 1969)

5 AUTHOR(S) (Last name, first name, initial)

Ronald A. Hankins and Michael Yankovich

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
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10 AVAILABILITY/LIMITATION NOTICES In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPOR/STINFO), Edwards, California 93523.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY AFRPL, Air Force Systems Command United States Air Force Edwards, California

13 ABSTRACT

(U) This report summarizes the work performed under Contract F04611-69-C-0021, entitled "Throttlable Primary Injector for Staged Combustion Rocket Engine". The objective of this program was to demonstrate a throttlable primary injector for a storable space engine employing the staged combustion cycle. The program goal was to demonstrate throttling over a 10:1 range.

(C) Specific accomplishments of the program were as follows: (1) completed the detailed design of a flightweight modular primary injector for the storable space engine using the HIPERTHIN injector concept, (2) demonstrated the injector over 90% of the desired throttling range (9K to 45K thrust), (3) established critical design and fabrication parameters for the HIPERTHIN injector concept, (4) demonstrated the performance of the HIPERTHIN injector through a chamber pressure range from 258 to 4390 psia and mixture ratio range from 10.7 to 27.0, (5) demonstrated durability by conducting 87 tests with one injector in excess of 200 sec, with durations ranging from 10 sec at high thrust to 72 sec at low thrust, and (6) conducted supporting studies to provide additional design data in the areas of fluid flow and low frequency instability.

DD FORM 1 JAN 64 1473

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Throttlable Injector						
Staged Combustion						
Primary Combustion						
Storable Propellant						

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